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AUTHORITY

AFSC ltr dtd 26 May 1972

AFML-TR-67-310

SEMI-RIGID OR NON-RIGID STRUCTURES FOR RE-ENTRY APPLICATIONS

J. F. Keville

Space-General, a Division of
Aerojet-General Corporation

September 1967

FINAL TECHNICAL REPORT AFML-TR-67

Project No. 7-943b

Part 3 Appendices

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Air Force Materials Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

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Air Force Materials Laboratory
Research and Technology Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

FOREWORD

This Final Technical Report covers all work performed under contract AF 33(657)-10252 from 15 January 1963 to 15 January 1967. The manuscript was released by the author September 1967 for publication as an RTD Technical Report.

This contract with the Space-General Plant, Aerojet-General Corporation, El Monte, California, was initiated under ASD (subsequently RTD) Project Number 7-943b, entitled "Semi-Rigid or Non-Rigid Structures for Reentry Applications." It was accomplished under the technical direction of Mr. Thomas Campbell, MATF (now ASKMM), of the Manufacturing Technology Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio.

Mr. J. F. Keville was the Program Manager for Space-General. Others who participated in the development, fabrication, and test work in this project were:

A. F. Baca, Stress and Loads Analyst
M. K. Barsh, Materials Systems Specialist
C. J. Barton, Vehicle Design Engineer
C. R. Burnett, Materials Engineer
J. E. Crawford, Manager, Expandable Structures Department
G. H. Fredy Jr., Test Engineering Supervisor
W. A. Grant, Welding Engineering
J. G. Guidero, Project Staff Engineer
W. Hatalsky, Aerodynamicist
J. S. Haynes, Test Engineer
C. S. Horine, Senior Engineer
J. C. Huisking, Manufacturing Engineer
J. D. McNerney, Aerodynamicist
J. V. Miller, Design Specialist
J. E. Misselhorn, Thermodynamicist
R. A. Morrison, Design Specialist
A. H. Olsen, Senior Engineer
R. B. Robinson, Materials and Processes Engineer
J. R. Schrink, Manufacturing Engineer
S. L. Tomkinson, Project Staff Engineer
F. Warren, Program Management Office
J. A. Wrede, Materials Scientist

In addition to these Space-General technical personnel, numerous other technicians and project support personnel, as well as subcontractor technical personnel, participated significantly in the completion of this work.

FOREWORD (Continued)

This project has been accomplished as a part of the Air Force Manufacturing Methods Program, the primary objective of which is to develop, on a timely basis, manufacturing processes, techniques and equipment for use in economical production of USAF materials and components.

Suggestions concerning additional manufacturing methods development required on this or other subjects will be appreciated.

This technical report has been reviewed and is approved.

C. H. Nelson

C. H. NELSON, Assistant Chief
Manufacturing Technology Division
Air Force Materials Laboratory

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ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

TABLES

Part 1 Evaluation and Design

TABLES (Continued)

Part 2 Fabrication and Test

LIST OF SYMBOLS

A	Reference Area
A_n	Acceleration, Normal
A_t	Acceleration, Tangential
c	Specific Heat of Materials, Btu/lb ^oF
c_p	Specific Heat, Btu/lb ^oF
C_D	Drag Coefficient
C_L	Lift Coefficient
C_n	Normal Force Coefficient
C_p	Pressure Coefficient
D	Boom Diameter, inches
E	Young's Modulus
Fg	Load due to Acceleration, pounds/inch
f_o	Force per Unit Length
f_s	Shear Fiber Load
f_t	Tension Fiber Load Due to Internal Pressure
F	Force
$\bar{i}$	Unit Vector in the x Direction
I	Moment of Inertia
$\bar{j}$	Unit Vector in the y Direction
$\bar{k}$	Unit Vector in the z Direction
k	Thermal Conductivity Btu/hr ft^2 ^oF/ft
Ku	Effective Sharp-Edged Gust Velocity, ft/sec
ℓ	Length of Boom from Apex

L/D	Lift-to-Drag Ratio
$\dot{m}$	Mass Ablation Rate
m	Mass per Unit Length
M_v	Keel Moment, inch-pound
M_y	Moment About the Horizontal Axis, inch-pound
M_z	Moment About the Vertical Axis, inch-pound
M	Bending Moment
n_g	Gust Load Factor, Normal to Flight Path
n_z	Gust Load Factor, Normal to Keel
N'/ql	Normal Span Loading
N_θ	Unit Hoop Load, pounds/inch
$N_{\phi B}$	Unit Longitudinal Bending Load, pounds/inch
$N_{\phi p}$	Unit Longitudinal Force Due to Internal Pressure pounds/inch
p	Internal Pressure, pounds/sq. inch
p_s	Boom Shear Unit Loads, pounds/inch
P_s	Increment of Internal Pressure Applied to a Strand
q	Dynamic Pressure, pounds/sq. ft.
$\dot{q}$	Heat Flux, Btu/sec ft^2
q_{cw}	Cold Wall Heat Flux, Btu/sq. ft., sec
$\dot{q}$	Pseudo Heat Flux, Btu/sq. ft., sec
q_ℓ	Heat Flux on Boom
q_s	Heat Flux on Boom at Stagnation Point

LIST OF SYMBOLS (Continued)

Q	Shear Force
Q_c	Heating Rate, Btu/sq. ft., sec
Q^*_c	Effective Heat of Ablation, Btu/lb
r_1	Radius of Curvature
r_2	Distance from Neutral Axis
R	Apex Radius
R_i	Instantaneous Radius
t	Time, sec., or Wall Thickness, in.
T_{av}	Average Temperature of Material During Time (dt), ^oR
T_i	Inside Surface Temperature, ^oR
T_i	Effective Average Inside Temperature of Material, ^oR
T_m	Ablation Temperature, ^oF
T_{psm}	Pseudo Melting Temperature, ^oF
T_s	Tension in a Longitudinal Strand
T_i	Inside Surface Temperature, ^oF
T_o	Outside Surface Temperature, ^oR
T_H	Tension in a Hoop Strand
V	Shear Load, pounds
w	Unit weight pounds/in
W	Weight, Pounds
W/C_DA	Ballistic Coefficient
W/s	Wing Loading
x, y, z	Coordinate System
$x'/q\ell$	Axial Span Loading

LIST OF SYMBOLS (Continued)

x/ℓ	Keel Station
y/ℓ	Span Station
α	Angle of Attack - Degrees
γ	Cone Semivertex Angle, Degrees
ϵ	External Emissivity at T_o
δ	Thickness of Material, ft.
η	Angle Between Velocity Vector and the Normal to the Surface
θ	Angular Change
θ_i	Re-entry Angle, Degrees
$\iota(\xi)$	E_ξ/E_{ξ_o}, Normalized to Unity at ξ
ξ	Nondimensional Length Coordinate, x/ℓ
Λ	Sweep Angle of L. E. Boom Relative to y-Axis
ρ	Ambient Air Density, lb/ft^3
ρ_m	Density of Material, lb/ft^3
σ	Stefan-Boltzmann Constant
σ_c	Pressure Stress in Cylindrical Section
σ_p	Pressure Stress
σ_s	Shear Stress
σ_t	Pressure Stress in Toroidal Section
$\varphi(\xi)$	Nondimensional Force Distribution Parameter
ψ	Nondimensional Parameter, $\frac{\ell^2 F}{EI_o}$
$\omega''(x)$	Transverse Beam Deflection
Ω	Nondimensional Frequency Parameter, $\frac{\ell^4 \omega^2 m_o}{EI_o}$

LIST OF SYMBOLS (Continued)

Subscripts

a	Aft Station
f	Forward Station
n	Normal Component
o	Apex

Appendix I

TORCH TEST PROCEDURE

APPENDIX I

TORCH TEST PROCEDURE

1.0 PURPOSE

This method is intended for use in determining the ablative characteristics of Silicone rubber specimens.

2.0 DISCUSSION

2.1 TEST SPECIMEN

The specimen shall be cured silicone rubber, measuring 5" dia x 1/4" thick.

2.2 TEST APPARATUS

For heating the specimens, an oxygen/acetylene torch using a Victor No. 12 tip shall be used. A holding fixture shall be used consisting of two asbestos plates. The top plate shall have a 5" dia hole in the center to accommodate the rubber specimen and the bottom plate shall have a 1/2" dia hole to accommodate a thermocouple wire to record the back side temperature of the rubber specimen.

A calibrating plate shall be used to determine the flame temperature. This plate shall consist of a 2" x 2" x 1/8" stainless steel plate, with a thermocouple embedded in a hole as close to the opposite surface as possible without rupturing the opposite surface.

2.3 TEST PROCEDURE

The oxygen/acetylene torch shall be placed in a position to impinge the flame on the center of the steel calibrating plate. The distance the torch is placed above the calibrating plate will be a function of the desired test temperature.

The specimen to be aged will be placed in the holding fixture next to the steel calibration plate before calibrating begins.

After the desired temperature has been obtained, the torch is pivoted to impinge the flame on the center of the rubber specimen maintaining the distance determined during calibration. A continuous recording of the back side temperature of the specimen will be recorded over the duration of the test.

2.4 CALCULATIONS

Test results will be reported as follows:

a. Ablation rate

$$\dot{X} = \frac{X_1 - X_2}{\Delta t}, \text{ inches per second}$$

X_1 = original thickness, inches

X_2 = aged thickness, inches

Δt = time specimen subjected to flame, seconds

b. Mass weight loss

$$\dot{W} = \frac{W_1 - W_2}{\Delta t} \text{ , pounds per second}$$

W_1 = original weight, lbs

W_2 = aged weight, lbs

Δt = time specimen subjected to flame, seconds

Appendix II

FABRIC REINFORCEMENT REQUIREMENTS

Requirement No. 335-R2
16 May 1963

FABRIC REINFORCEMENT REQUIREMENTS

I. OBJECTIVE

A. High temperature resistant fabric suitable for impregnating and coating with an elastomeric heat resistant and/or ablation material such as silicone rubber.

B. High strength-to-weight ratio at room temperature and elevated temperature.

C. High stress-rupture and fatigue strengths.

D. Good tear resistance and ductility.

E. High bending flexibility.

F. High crease resistance and bending recovery without significant loss of strength.

G. Ease of forming to component contour.

H. Ability to make flexible seams or joints such as by brazing or spot welding.

I. High reliability.

J. Currently available materials.

K. Economical cost.

II. APPLICATION

A. Inflatable paraglider to re-enter earth atmosphere from space at hypersonic velocity. Overall tentative dimensions of the paraglider are shown in attached sketch no. 335-SK 1. The paraglider consists of three tapered inflatable booms approximately 17 feet long x [illegible] inch OD x 16 inch OD. These three booms are joined to a common vertex by a 56.6 inch outer radius toroidal section. Fastened between the center keel boom and the outer leading edge booms is a flexible wing membrane.

B. The purpose of the metal (or glass) fabric is to retain the geometrical shape of the vehicle in the inflated sections and reinforce the wing membrane. Two methods of manufacture are contemplated: (a) the fabric is coated by spreading, dipping, or calendering of the silicone as a flat material and then applied to the tooling form where the joints are vulcanized or similarly fastened, (b) the bare fabric is applied to the tooling form and brazed, spot-welded, or similarly fastened at the joints after which it is coated with the silicone material.

C. The thickness of silicone rubber on the wire or glass cloth may range from 0.010 inches to 0.15 inches depending on heat resistant and ablative properties.

III. REQUIREMENTS

A. Vehicle shall be flexible in original condition permitting packaging like life raft or parachute.

B. Total storage time folded and packaged in space vehicle or capsule at nominal earth atmosphere (composition and pressure) and room temperatures, ranges from few days to one year. The silicone matrix is assumed semi-permeable to the atmosphere (consider oxidation, etc.).

C. Vehicle exposed to outer space environment (principal consideration - high vacuum) after release from space station and deployment to inflated condition. Time in space vacuum approximately 30 minutes before re-entering sensible earth atmosphere.

D. Time from re-entering sensible atmosphere at approximately 400,000 feet altitude to landing on the ground is approximately 30 minutes during which time high re-entry heating occurs for approximately 15 minutes above 1000°F. Maximum structural temperature at any point including certain joint areas is assumed to be about 1000°F.

E. The inflatable sections are pressurized to approximately 11 psi above the external ambient pressure prior to entering the atmosphere and during the remaining flight to landing.

F. The maximum actual hoop load in a boom is 176 pounds per inch in tension (constant).

G. Under critical aerodynamic loading, the actual longitudinal load in a boom varies from a maximum of 159 pounds per inch to a minimum of 7 pounds per inch in tension.

H. Tension loads in the apex are substantially higher than above. Final design will use multiple plies in this area (see item K below).

I. The maximum actual shear load in a boom is 15.4 pounds per inch due to beam bending.

J. The maximum actual shear load in the apex is 33 pounds per inch due to torsion and some beam bending.

K. The above loads may be carried by one or two (or possibly more) plies of reinforcing cloth depending on the effect on ease of fabrication or degree of flexibility. Minimum number of plies is desirable. Best design may be two ply with second ply in bias direction.

L. Wing membrane load is a maximum of 2 pounds per inch in tension due to aerodynamic pressure.

M. The fabric shall not exceed 50% of its ultimate corresponding strength when exposed to the above loads at temperatures from 70° to 1000°F.

N. Stability and integrity (including strength to withstand maximum loads) of fabric must be retained during and after re-entry heating. (Sufficient retained flexibility is required to withstand dynamic airloads, maneuver loads, and landing loads.)

O. Quantities required.

1. Experimental: 3 square feet minimum

2. Pilot test: approximately 30 square feet

3. Full scale components construction: 600 to 2000 square feet

IV. TECHNICAL INFORMATION REQUIRED

A. Product or products recommended with full details of materials, sizes, thickness, weaves, etc.

B. Fabrication details (method of fabricating each: filaments, strands, cloth, etc). If another source is to be utilized for materials such as filaments or special coatings, stranding, or other; please supply details.

C. Cloth physical data: - all properties should be expressed as function of temperature from -40°F to 1200°F (or higher) and after re-cooling to room temperature. Details of methods of testing are required. Indicate whether data are average values or guaranteed minimums, number of specimens tested, scatter, and reproducibility of data. Include references if not tested by firm responding to this inquiry.

1. Tensile strength: ultimate, yield (if applicable), stress rupture, and tensile fatigue.

   a. Warp direction

   b. Fill direction

   c. 2:1 biaxial loading

   d. 1:1 biaxial loading

2. Deformations for the conditions of item 1.

   a. Strain in direction of and transverse to load vs applied load

   b. Ductility (% elongation at failure)

   c. Creep (short time) at temperature

3. In-plane shear strength and shear rigidity.

4. Tear strength.

5. Minimum bend radius

   a. For zero permanent set

   b. For no fracture

6. Bending flexibility.

7. Bending fatigue strength (wrinkle and fold endurance).

8. Loss of strength due to bending and sharp crease folding.

9. Weight per unit area.

10. Thickness

11. Percent cloth volume which is void (to be filled by coating material)

12. Since coated properties may vary from uncoated properties, above properties of fabric with silicone (or similar) elastomer coatings are also desired wherever available.

D. Oxidation resistance.

E. Effect of exposure to space environment.

F. Formability to contours (cylinders, cones, toroids, spheres, etc.)

G. Compatibility with silicone elastomers for adhesion. Possible surface preparation required.

H. Recommended method of making joints (brazing, spot welding, bonding, sewing, etc.) together with any supporting data on strength of joints or similar information.

I. Quality assurance techniques to be employed.

J. Provide additional information or recommendations based on supplier research and application experience.

V. ADDITIONAL INFORMATION REQUIRED

A. Capabilities

1. Provide technical discussion or company brochure covering products, capabilities, related applications, fabricating techniques, etc.

including supporting data. Furnish information on facilities and personnel for conducting development and production work.

2. Provide similar information including addresses on subcontractors and sources of supply to be utilized or recommended.

B. Prices for recommended and alternate fabrics.

1. Standard supplier quantity breakdown.

2. Quantities shown in item III-O.

C. Availability

1. Lead time for currently available recommended products in quantities specified.

2. Expected development effort required for improved products to meet specified requirements.

Appendix III

REPORT ON RESISTANCE WELDING EVALUATION

SCIAKY BROTHERS, INC.

(B. F. Goodrich Co. Report LC-1249)

LC-1249
Aug. 24, 1964

B.F.GOODRICH COMPANY
AKRON, OHIO

I. OBJECT:

1. Determine the resistance welding method for the fabrication of assemblies constructed of ultra-fine nickel-chromium wire mesh.

2. Make comparable overlapping weld tests using pulsating A.C. current, pulse (spike) current, and condenser discharge current.

3. Prepare tensile test specimens and determine joint efficiency.

4. Determine whether suitable series welds can be made without burning the fabric between the conductors.

5. Determine whether or not aluminum can be used as a back-up current conductor for series welding.

6. Determine joint efficiency obtainable for a double row of overlapping spot welds at minimum allowable row spacing.

7. Weld 3, 4 and 5 plies.

II. MACHINES USED:

SPO-0-58-2-3-220 #8134
2,300 maximum short circuit secondary amps

PMMOC-50-36-440 #6937
8,000 maximum short circuit secondary amps

III. MATERIAL USED:

1.0 mil. ultra-fine nickel-chromium wire mesh two by two basket weave (58 x 58). See Figure I.

Fabric Tensile Properties at 70°F
(Information supplied by B.F.Goodrich Co.)

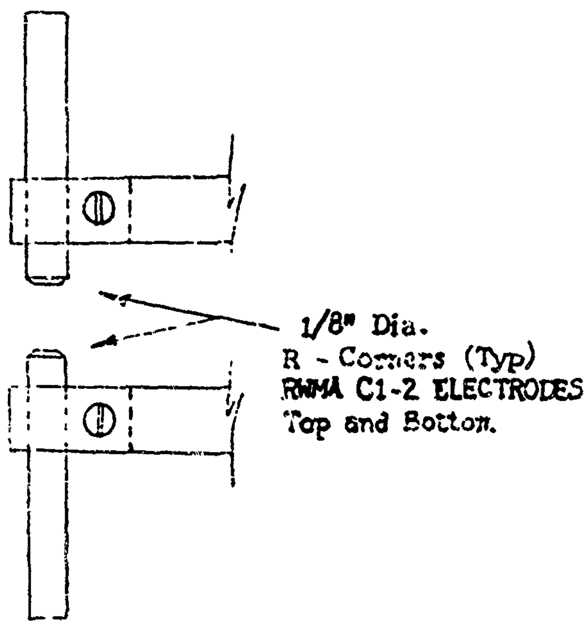
Test No.	Yield Load Warp	Yield Load Fill	Yield Elongation (%) Warp	Yield Elongation (%) Fill	Rupture Load (lbs/inch) Warp	Rupture Load (lbs/inch) Fill	Rupture Elongation (%) Warp	Rupture Elongation (%) Fill	Tensile Modulus (lbs/in.) Warp	Tensile Modulus (lbs/in.) Fill
1	340	368	9.2	1.8	375	407	16.0	10.0	7,870	23,720
2	357	362	8.7	1.9	397	405	15.6	9.4	8,980	25,700
3	353	367	8.3	1.9	387	413	15.1	7.4	7,810	23,670
4	357	354	8.7	2.2	382	402	15.3	7.7	7,660	22,870
5	353	-	9.3	-	397	-	15.9	-	7,950	-
AVE.	352	363	8.8	1.95	388	407	15.6	8.6	8,054	23,990

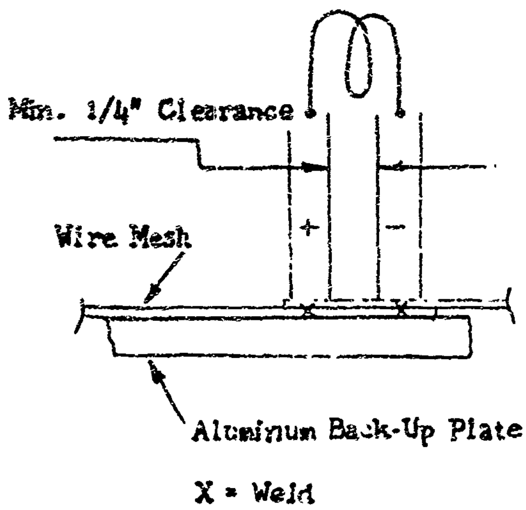
B.F.GOODRICH COMPANY
AKRON, OHIO

IV. MACHINE SETTINGS:

See BFG Drawing No. 1A1660, Sheets 1 through 8, attached.

V. PROCEDURE:





SEC. OF WELDING MACHINE

LC-1249
Aug. 24, 1964

B.F.GOODRICH COMPANY
AKRON, OHIO

Material was degreased by the following cleaning procedure:

1. Acetone dip
2. Distilled water
3. 10% Concentration of HCl (10-60 seconds)
4. Distilled water
5. Acetone dip
6. Dry (6-360 seconds)

NOTE: Parts were cleaned by B.F.Goodrich Co. prior to welding.

VI RESULTS:

Pulsating A.C. current, pulse (spike) current, and condenser discharge current types of resistance welding were attempted. No appreciable difference was noted. Since the production application called for overlapping spots or seam welding, the remainder of the work was accomplished on our Sciaky PMMOC-50-36-440 seam welder.

Joint efficiency of 80% (weld setting 3-27) on two ply single row and 85% (weld setting 4-35) on two ply double row welds was achieved.

Double row series welds were attempted to determine row spacing and type of back-up. Overlap spot welds spaced a minimum of 1/4" apart on copper back-ups produced seams with a joint efficiency of 62% (two ply only).

Joint efficiency on 3, 4, and 5 ply mesh is shown below:

Specimen #	No. of Ply	Row	Load	Joint Efficiency	Remarks
7-43	3	Single	268	67%	Clean break at weld line
10-60	3	Double	320	80%	Clean break at weld line
5-41	4	Single	220	55%	Clean break at weld line
10-61	4	Double	260	65%	Clean break at weld line
5-42	5	Single	180	45%	Wires burned
	5	Double		-	Not attempted

VII. CONCLUSION:

Welds with a joint efficiency of 85% on two ply and 80% on 3 and 4 ply wire mesh were achieved. Four and 5 ply welds are not recommended for high-strength joints. Double row direct welding is preferred over double row series welding.

Prepared by: ______________________ and ______________________
Alex Chiaro Paul Yankala

Approved by: ______________________
[illegible]

SGC PROJECT FIRST - RESISTANCE WELDING DATA SHEET

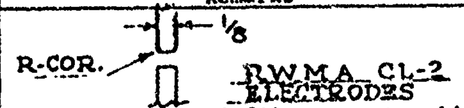
TEST LOCATION: Sciaky, Chicago DATE: 6/2/64

MATERIAL: Metal Fabric - High Temp. Nickel-Chromium Alloy per Spec. AGC 74036

FIRST WARE (REF.) SPECIMENS TAKEN FROM PILOT RUN PER DRAWING NO. 335 SK-4 (Salvage)

MACHINE NO. 8134 SPO-0-58-2-3 - Bench Welder

BFG SAMPLE NO. 2 Welding Method Pulsation A.C. (Preliminary)

Specimen No.	------Machine Setting------- Pressure	Time	Current	Type of Specimen	Type Of Weld	Load at Failure	Remarks
2-1	28 PSI	1/2	100%	Lap	One Spot	-	
2-2	"	"	"	"	"	8 lbs.	
2-3	"	"	"	"	"	12 lbs.	
2-4	40 PSI	1 cycle	"	"	"	-	Cut several metal filaments at weld.
2-5	55 PSI	"	"	"	"	-	No reading taken.
2-6	Fill	(Ref.)	-	Plain 1/2" W	None	164 lbs.	Jaw Break.
2-7	55 PSI	1 cycle	100%	Lap - 9 spots	Single Row	55	Failed at edge of weld.
2-8	Fill	(Ref.)	-	Plain 1/2" W	None	None	Slipped ends out of jaws.
2-9	55 PSI	1 cycle	90%	Lap - 9 spots	Single Row	52	Failed at edge of weld.
2-10	Fill	(Ref.)	-	Plain 1/2" W	None	166 lbs.	Jaw Break.
2-11	Fill	(Ref.)	-	"	None	200 lbs.	"
2-12	Fill	(Ref.)	-	"	None	164 lbs.	"
2-13	55 PSI	1 cycle	90%	Lap	Single Row	150 lbs.	Failure at edge of weld.
2-14	55 PSI	1 cycle	90%	Lap	1-1/2 Row	140 lbs.	Failure at edge of half row weld.
2-15	55 PSI	1 cycle	90%	Lap	Double Row Exposed	112 lbs.	Failure at edge of weld-unbalanced pull.
2-16				Mounted	Weld Section Double Row		Good fusion of welded nuggets.
2 17	55 PSI	1/2 cyc.	100%	Lap	18 spot total Single Row	108 lbs.	Failed at edge of weld.
2-18	55 PSI	1/2	80%-50%	Lap	Single Row each	40 lbs. (Ref.)	Ins, ted appearance in range

Witnessed By Date 6/2/64 Dwg. By ____________ BFG DRAWING NO.

Checked By ____________ 1A1660

Sciaky BFG

Date 6/2/64 Sheet 1 of 8

Sciaky BFG

SGC PROJECT FIRST - RESISTANCE WELDING DATA SHEET
TEST LOCATION: Sciaky, Chicago DATE: 6/3/64

MATERIAL: Metal Fabric - High Temp. Nickel-Chromium Alloy Per Spec. AGC 74036
FIRST WARP (REF.) SPECIMENS TAKEN FROM PILOT RUN PER DRAWING NO. 335 SK-4 (Salvage)
Machine No. 8134 SPO-0-58-2-3

(1) "AC" Pulsation (3) "CD" Cond. Disch.
(2) Pulse Weld (4) Series

BFC Sample No. & Specimen No. Welding Method

Specimen No.	Electrode Pressure (58# @ 80 psig)	Time: Power Adj.	Time: Cycle	Current: Voltage	Current: %	Type of Specimen Ravelled to 1" Width	Type of Weld	Spots	Load at Failure	1	2	3	4	Remarks
2-19	70 psig		½		60%	1" x 4", Lap Seam	Single Row	29	240#	AC				Good break few filaments not welded
2-20	70 psig	30		400		1" x 4", Lap Seam	Single Row	29	210#		P			Good break (Ref) Est. 10% of filmts. not welded
1-21	70 psig	30		400		1" x 4", Lap Seam	Single Row	29	276#			CD		Break at both sides of welded row
1-22	(Fill Specimen Ref)					Plain	None		400#					Agrees with strength of material jaw-break.
1-23	70 psig		½		65%	1" x 4", Lap Seam	Double Row	29 ea.	306#	AC				Tilt appearance - break along weld-row.
1-24	62 psig	90		1250v		1" x 4", Lap Seam	Double Row	29 ea.	198#			CD/S		1st Try with series weld using 1/8" aluminum back-up (weld on teflon and bare)
1-25	62 psig	90		1250v		1" x 4", Lap Seam	Double Row	29 ea.	160#			CD/S		Used insulator 1st - re-run with bare 1/8" alum.
1-26	62 psig	90		1250v		1" x 4", Lap Seam	Double Row	29 ea.	244#			CD/S		1/4" O.C. Rows with Copper back-up

WITNESSED BY ________ DATE 6/3/64

Sciaky BFG BFG

DWG. BY ________
CHECKED BY ________
DATE 6/2/64

BFG DRAWING NO. 1A1660

SCC PROJECT FIRST - RESISTANCE WELDING DATA SHEET

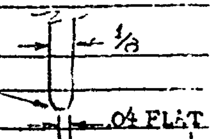
TEST LOCATION: Sciaky, Chicago DATE: 6/4/64

MATERIAL: Metal Fabric - High Temp. Nickel Chromium Alloy Per Spec. AGC 7436

FIRST WARP (Ref) SPECIMENS TAKEN FROM PILOT RUN PER DRAWING NO. 335 SK-4 (GALVAGE)

(#3 tested on 6/5/64) (Machine No. PMMOC 50-36 MN 6937)

BFG Sample No. 3 and 4 Width 1" Welding Method - AC-Seam Welding



Specimen No.	Layers	MACHINE SETTING 1/8" Electrode Wheel 2" Dia. Motor Speed Setting	Inch/ Min.	Wheel Pressure lbs.	Spot/ Inch	PHASE SHIFT Cool Cycle	Time Cycle	Heat %	Type of Seam Weld	Load at Failure lbs.	Remarks
3-27	2	22	21	50	55	1	½	53%	Single Row	320	Few unwelded filaments, slight high heat appear.
3-28	2	22	21	50	55	1	½	53%	Double Row	310	High heat appearance, weld rows 3/8 apart.
3-29	2	22	21	50	55	1	½	47%	Double Row	331	Good weld - impression marks on filaments.
4-30	2	22	21	50	55	1	½	42%	Single Row	90	Insufficient Heat (or weld).
4-31	2	22	21	50	55	1	½	47%	Single Row	230	Number of filaments were not welded.
4-32	2	22	21	50	40	2	½	53%	Sing Row	280	Number of filaments were not welded.
4-33	2	22	21	50	40	2	½	53%	Double Row	331	Clean Break - Lt. to Rt. Filament appeared to be nicked.
4-34	2	22	21	50	22	3	½	53%	Double Row	310	Break occurred along weld row - unbalanced tension.
4-35	2	22	21	30	40	2	½	50%	Double Row	340	Good surface appearance (noted reduced nicks on filament.
4-36	2	22	21	30	40	2	½	50%	Single Row	240	Good surface appearance (few unwelded filament good flex. cond.).
5-37	3	"	"	30	40	2	½	70%	Single Row (3P)	220	Good specimen.
5-38	3	"	"	30	40	2	½	70%	Double Row (3P)	175	Poor specimen - insufficient edge distance.
5-39	3	"	"	30	40	2	½	70 1st 75 2nd	Double Row	300	Failed at second pass.
5-40	3	"	"	30	40	2	½	73%	Double Row	280	Failed at second pass.
5-41	4	"	"	30	40	2	2 (½)	80%	Single Row	220	Pile-up or weld crease caused burn.
5-42	5	"	"	30	40	2	2 (½)	80%	Single Row	180	Pile-up or weld crease caused burns.

DATE 6/4/64

BFG DRAWING NO. 1A1660

Sciaky Sciaky

Sheet 3 of 8

S : PROJECT FIRST - RESISTANCE WELDING DATA SHEET

TEST LOCATION: Sciaky, Chicago DATE: 6/8/64

MATERIAL: Metal Fabric - High Temp. Nickel-Chromium Alloy per Spec. AGC 7436

FIRST WARP (REF.) SPECIMENS TAKEN FROM PILOT RUN PER DRAWING NO. 335 SK-4 (Salvage)

(Machine No. — PMMOC 50-36 MN 6957)

BFG SAMPLE NO. 7 and WIDTH 1" Welding Method - AC - Seam Welding

		MACHINE SETTING					PHASE SHIFT				Remarks
Specimen No.	Layers	Motor Speed Setting	Inch/ Min.	Wheel Pressure lbs.	Spot/ Inch	Cool Cycle	Time Cycle	Heat % Series	Type of Seam Weld	Load at Failure lbs.	
7-37	3	22	21	30	68	1	½	69	Single Row	250	Number of fil. unwelded on surface.
7-38	"	"	"	35	"	"	"	"	"	210	Wires welded - low shear.
7-39	"	"	"	"	"	"	"	75	"	150	(Machined wheel track to .080".
											(Welded area 7/8" instead of 1".
7-40	"	"	"	"	"	"	"	"	"	180	Sheared at weld line.
7-41	"	"	"	40	"	"	"	"	"	200	Sheared at weld line.
7-42	"	"	"	"	49	2	"	"	Two Rows	170	Sheared at weld line.
2"DIA.	1/8"										
(TYP) R	COR.		.04 & .08								
			RW MA CL-2								

DATE 6/8/64

BFG DRAWING NO. 1A1660

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Sheet 4 of 8

SGC PROJECT FIRST - RESISTANCE WELDING DATA SHEET
TEST LOCATION: Sciaky, Chicago DATE: 6/9/64

MATERIAL: Metal Fabric - High Temp. Nickel-Chromium Alloy Per Spec. AGC 7436
FIRST WARP (REF) SPECIMENS TAKEN FROM PILOT RUN PER DRAWING NO. 335 SK-4 (Salvage)
(Machine No. PM10C 50-26 MN 6937)

BFG SAMPLE NO. 7 & WIDTH 1" WELDING METHOD - AC-Seam Welding

Specimen No.	Layers	MACHINE SETTING Motor Speed Setting	Inch/ Min.	Wheel Pressure lbs.	Spot/ Inch	Cool Cycle	Time Cycle	PHASE SHIFT Heat % Series	Type of Seam Weld	Load at Failure lbs.	Remarks
7-43	3	22	21	40	49	2	½	72	Single Row	268	Clean break at weld line.
7-44	"	"	"	"	"	3	"	"	"	150	Clean break at weld line. (Too hot)
7-45	"	"	"	"	"	"	"	60	"	170	Clean break at weld line. (Too hot)
CHANGED ABOVE SET-UP FOR ANOTHER JOB.											
				6/10/64 NEW SET-UP							
7-46	3	22	21	35	49	3	½	85	Single Row	120	Number of filaments were not welded.
7-47	3	"	"	"	"	"	"	"	Double Row	150	Number of filaments were not welded.
2" DIA. 1/8"											
(TYP.) R COR.			.04 & .08								
			RWMA CL·2								

DATE 6/9/64

Sciaky Sciaky

BFG DRAWING NO.
1A1660

Sheet 5 of 8

SGC PROJECT FIRST - RESISTANCE WELDING DATA SHEET
TEST LOCATION: Sciaky, Chicago DATE: 6/10/64

MATERIAL: Metal Fabric - High Temp. Nickel Chromium Alloy Per Spec. AGC 7436
FIRST WARP (REF) SPECIMENS TAKEN FROM PILOT RUN PER DRAWING NO. 335 SK-4 (Salvage)
(Machine No. PMOC-50-36 MN 6937)

BFG SAMPLE NO. 7 & 8 WIDTH 1" WELDING METHOD - AC - Seam Welding

		MACHINE SETTING					PHASE SHIFT				
Specimen No.	Layers	Motor Speed Setting	Inch/ Min.	Wheel Pressure lbs.	Spot/ Inch	Cool Cycle	Time Cycle	Heat %	Type of Seam Weld	Load at Failure lbs.	Remarks
7-48	3	22	21	35	49	2	½	85	Double Row	150	Clean break at weld line. Poor surface appearance.
8-49	3	22	21	"	"	"	"	75	"	110	Few unwelded. Fil.
			(PRESSURE TOO LOW IN THE SETTINGS ABOVE)								
8-50	3	22	21	50	49	2	½	75	Double Row	180	Clean break at weld line. Weld too hot.
8-51	"	"	"	"	"	"	"	70	"	240	" (Good appearance)
8-52	"	"	"	"	"	"	"	"	"	200	" "
2" DIA.	1/8"										
(TYP) R COR.			.04 & .08								
			RWMA CL-2								

DATE 6/10/64

BFG DRAWING NO. 1A1660

Sciaky Sciaky

Sheet 6 of 8

SGC PROJECT FIRST - RESISTANCE WELDING DATA SHEET

TEST LOCATION: Sciaky, Chicago DATE: 6/11/64

MATERIAL: Metal Fabric - High Temp. Nickel-Chromium Alloy Per Spec. AGC 74036

FIRST WARP (REF.) SPECIMENS TAKEN FROM PILOT RUN PER DRAWING NO. 335 SK-4 (Salvage)

(Machine No. PMCO-50-36 S/N 6937)

BFG SAMPLE NO. 9 & 10 WELDING METHOD AC - SEAM WELDING

		MACHINE SETTING 1/8" Electrode Wheel 2" Dia.					PHASE SHIFT				
Specimen No.	Layers	Motor Speed Setting	Inch/ Min.	Wheel Pressure lbs.	Spot/ Inch	Cool Cycle	Time Cycle	Heat %	Type of Seam Weld	Load at Failure lbs.	Remarks
9-53	3	22	21	50	43	2	1	60	Double Row	275	Clean break at weld line (good appear.)
9-54	"	"	"	"	"	"	"	"	"	280	" 68%
9-55	"	"	"	"	34	3	"	"	"	275	"
9-56	"	"	"	"	34	3	"	"	"	180	Not welded.
10-57	"	"	"	"	"	"	"	65	"	240	Clean break at weld line
10-58	"	"	"	"	57	1	1	60	"	270	"
10-59	"	"	"	"	43	"	2	48	"	288	"
2" DIA.	1/8"										
(TYP) R COR.			.04 & .08								
			RWMA CL-2								

WITNESSED BY ______________ DATE 6/11/64 BFG DRAWING NO. 1A1660

Sciaky BFG Sciaky

Sheet 7 of 8

SGC PROJECT FIRST - RESISTANT WELDING DATA SHEET

TEST LOCATION: Sciaky, Chicago DATE: 6/12/64

MATERIAL: Metal Fabric - High Temp. Nickel-Chromium Alloy Per Spec. AGC 74036

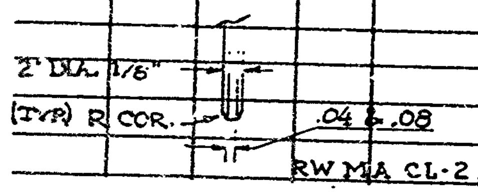
FIRST WARP (REF.) SPECIMENS TAKEN FROM PILOT RUN PER DRAWING NO. 335 SK-4 (Salvage)

(MACHINE NO. PMNOC-50-36 S/N 6937)

BFG SAMPLE NO. 10

WELDING METHOD - AC - Seam Welding

		MACHINE SETTING				39 gage	PHASE SHIFT					
		1/8 Electrode Wheel 2" Dia.										
Specimen No.	Layers	Motor Speed Setting	Inch/ Min.	Wheel Pressure lbs.	Spot/ Inch	Cool Cycle	Time Cycle	Heat %	Type of Seam Weld	Load at Failure lbs.	Remarks	
10-60	3	22	21	50	43	1	2	48	Double Row	320	Good appear'ng weld - clean break at weld line.	80%
10-61	4	"	"	55	"	"	"	55	"	250	"	
10-62	4	"	"	"	"	"	"	50	"	150	Failure at 2nd pass (insufficient heat).	
10-63	4	"	"	"	"	"	"	55	"	240	Good appearing welds. Clean break at weld line.	



WITNESSED BY ____________ DATE 6/12/64

Sciaky ____ BFG ____ Sciaky ____

DWG BY ____

CHECKED BY ____

DATE 6/ /64

BFG DRAWING NO. 1A1660

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Appendix IV

QUALIFICATION TEST ANALYSIS

Project FIRST

Comparison of Tensile Strengths of 2, 3, 4, and 5 Layer Welds in Nickel-Chromium Fabrics with the Tensile Strength of the Unwelded Parent Fabric

1.0 GENERAL

Tensile strengths of 2, 3, 4 and 5 layer resistance lap welded Karma fabrics were compared with the tensile strength of unwelded fabric. The test coupons were one inch wide with 58 yarns and gage length of two inches. The welding machine was tested at its lowest operating speed, 2.0 inches of weld per minute, and at its highest operating speed, 8.4 inches of weld per minute.

The variation in welding procedure and the number of test samples that were tested were as follows:

a. 25 coupons of each of the 2, 3, 4 and 5 layer material using the lower arm of the welding machine and set at low speed.

b. 6 coupons of each of the 2, 3, 4 layer material using the center arm of the welding machine and set at low speed.

c. 6 coupons of each of the 2, 3, 4 layer material using the lower arm of the welding machine and set at high speed.

d. 6 coupons of each of the 2, 3, 4 layer material using the center arm of the welding machine and set at high speed.

The average of all coupons (154 total) was 83.3% joint efficiency at 90% confidence, or 85.0% efficiency by arithmetic mean.

The 2 and 3 layer resistance lap material coupons which were welded using the lower arm and low speed of the welding machine, were from Roll #7 and were compared with 8 coupons of the parent material from Roll #7 material. The remainder of the welded coupons were from Roll #1 and were compared with 12 coupons of the parent material from Roll #1 material.

2.0 ANALYSIS

2.1 By means of the "t" test, as outlined in paragraph 3.0, it was determined that there is over 99.95% confidence that the average tensile strength of the welded material exceeds 70% of the average tensile strength of the parent material.

2.2 As indicated in Tables I, II, III and IV, at 90% confidence, the average tensile strength for welded material is 78 to 89% of the average tensile strength of the parent material.

TABLE I

Material Welded Using Lower Arm and Low Speed

No. of Layers	Avg. Parent Mat'l. (lb/in)	Avg. Welded Mat'l. (lb/in)	% of Avg. Welded to Avg. Parent Mat'l.	Lower 90% Confidence Limit of Avg. Welded Strength (lb/in)	% of the Lower Limit Avg. to Parent Mat'l.
2	347.74	290.04	83.5	280.73	80.7
3	347.74	291.48	83.6	281.89	81.1
4	334.67	290.	86.7	284.16	84.8
5	334.67	302.96	90.5	299.52	89.4

TABLE II

Material Welded Using Center Arm and Low Speed

No. of Layers	Avg. Parent Mat'l. (lb/in)	Avg. Welded Mat'l. (lb/in)	% of Avg. Welded to Avg. Parent Mat'l.	Lower 90% Confidence Limit of Avg. Welded Strength (lb/in)	% of the Lower Limit Avg. to Parent Mat'l.
2	334	289.33	86.5	283.5	84.6
3	334	284.17	85.2	276.3	82.5
4	334	270.67	81.0	264.7	79.0

TABLE III

Material Welded Using Lower Arm and High Speed

No. of Layers	Avg. Parent Mat'l. (lb/in)	Avg. Welded Mat'l. (lb/in)	% of Avg. Welded to Avg. Parent Mat'l.	Lower 90% Confidence Limit of Avg. Welded Strength (lb/in)	% of the Lower Limit Avg. to Parent Mat'l.
2	334	282.50	84.6	277.9	83.5
3	334	274.5	82.2	272.4	81.5
4	334	279.3	83.6	277.0	83.0

TABLE IV

Material Welded Using Center Arm and High Speed

No. of Layers	Avg. Parent Mat'l. (lb/in)	Avg. Welded Mat'l. (lb/in)	% of Avg. Welded to Avg. Parent Mat'l.	Lower 90% Confidence Limit of Avg. Welded Strength (lb/in)	% of the Lower Limit Avg. to Parent Mat'l
2	334	279.00	83.5	275.0	82.3
3	334	274.67	82.2	271.7	81.2
4	334	264.16	79.1	261.8	78.0

2.3 To further demonstrate the meager reduction in tensile strength following the welding procedure, a comparison was made of the weakest welded coupons in each of the four categories listed above and the strongest of the corresponding parent material. This worst observed case is summarized in Table V.

TABLE V

Welding Arm	Welding Speed	Weakest Coupon Tensile Strength (lb/in)	Strongest Parent Mat'l. Tensile Strength (lb/in,	Percentage of Weakest to Strongest (%)
Lower	Low	260	364*	71.4
Lower	Low	270	341	79.2
Center	Low	259	341	75.9
Lower	High	270	341	79.2
Center	High	260	341	79.3

*This parent material is from Roll #7 material strip (the remainder of the coupons are taken from Roll #1).

3.0 METHOD OF ANALYSIS FOR "t" TEST

The value of "t" is calculated by the following formula:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_p\sqrt{\frac{1}{N_1} + \frac{1}{N_2}}} \quad \text{where}$$

$\bar{X}_1$ is the arithmetic average of one set of data

$\bar{X}_2$ is the arithmetic average of the other set of data

N_1 is the number of samples used to determine $\bar{X}_1$

N_2 is the number of samples used to determine $\bar{X}_2$

$$\text{and } S_p^2 = \frac{\sum X_{1i}^2 - \frac{\left(\sum X_{1i}\right)^2}{N_1} + \sum X_{2i}^2 - \frac{\left(\sum X_{2i}\right)}{N_2}}{N_1 + N_2 - 2}$$

and t is tabulated in any statistics textbook for various confidence levels and degrees of freedom where the degrees of freedom = $N_1 + N_2 - 2$.

For the present case $\bar{X}_2$ is considered the unknown average for which we wish to be 90% confident that $\bar{X}_1$ exceeds it. So in the tables we find t = 1.31 for $N_1 = 25$, $N_2 = 8$ (the number of samples in the parent population for the two and three layer case) or $N_1 + N_2 - 2 = 31$. Similarly, t = 1.30 for $N_1 = 25$, $N_2 = 12$ (the number of samples in the parent population for the four and five layer case) or $N_1 + N_2 - 2 = 35$. In those cases where $N_1 = 6$ and $N_2 = 12$, t = 1.34 (since $N_1 + N_2 - 2 = 16$).

Prepared by Space-General Corporation Reliability Department.

Appendix V

STATISTICAL ANALYSIS OF WELD STRENGTH WITH 0.050" UPPER ELECTRODES

STATISTICAL ANALYSIS OF WELD STRENGTH WITH 0.050" UPPER ELECTRODES

A. CONFIDENCE LEVEL THAT AVERAGE EXCEEDS 85%

Parent fabric strength is 316 lb/in.

$.85\,(316) = 268.6$

Average of 29 valid coupon tests is 283.6 lb/in.

$\Sigma X = 8225$

$\bar{X} = 283.6$

$\Sigma (X^2) = 2{,}336{,}629$

$\frac{(\Sigma X)^2}{29} = 2{,}332{,}780$

$\Delta = 3{,}849$

$s^2 = \frac{3849}{29-1} = 137.5$

$s^2_{\bar{X}} = \frac{137.5}{29} = 4.74$

$s_{\bar{X}} = 2.18$

Set $t = \frac{283.6 - 268.6}{2.18} = \frac{15.0}{2.18} = 6.90$

There is more than 99.95% confidence that the average tensile strength (warp) of a two layer weld exceeds 85% of the average tensile strength of parent fabric.

B. DETERMINE TENSILE STRENGTH AT 90% CONFIDENCE LEVEL

Set $t = 1.311 = \frac{283.6 - X}{2.18}$,

$X = 283.6 - 2.85 = 280.8$

$\frac{280.8}{316} = 0.8885$

Therefore, there is 90% confidence that the average tensile strength (warp) of a two layer weld exceeds 88.85% of the average tensile strength of parent fabric.

Appendix VI

TEST MODEL SIMILARITY STUDY

Appendix VI

EST MODEL SIMILARITY STUDY

STRUCTURAL SIMILARITY LAWS

Structural modeling for static and dynamic loads is a common practice for evaluating the strength and vibration characteristics of complex structures. The basic parameters scaled for model analysis are strength (material thickness, buckling coefficients, etc.), flexibility (modulus, area moment of inertia, etc.), and dynamic response (mass, weight distribution, stiffness, etc.).

An inflatable structure has unique features affecting scaling. The flexible fabric has non-linear load-deflection characteristics, and these characteristics usually vary with changes in thickness. Also, the load-deflection characteristics of the pressurized structure are a function of the magnitude of the internal pressure, the geometry of the structure and the cloth orientation.

In scaling the thickness of the fabric, the non-homogeneous orthotropic (or anisotropic) properties of the material must be considered. Scaling of a single cloth parameter such as strength or thickness will cause changes in other properties such as stiffness or directional behavior. These resulting changes may vary from being proportional to the original parameter change, to being erratic, or to being inversely proportional. The development problems associated with obtaining proportional changes in all fabric properties may be avoided by maintaining the fabric invariant during scaling.

Thermodynamic considerations such as heat transfer, thermal stresses, and changes in material properties comprise another set of conditions which may be scaled for similitude under a varying temperature operational environment. However, these factors are difficult to simulate in a laboratory and an approximation of worst conditions will usually suffice for structural evaluation. Peak operational temperature and distribution along the vehicle surface is held constant while thermal shock conditions are allowed to vary somewhat.

The scaling ratios for an inflatable paraglider are basically the same as for any pressure-stabilized thin shell of revolution. However, in the following derivations of the similitude relationships, the wall thickness (t) is an equivalent value based on fiber diameter, fiber orientation, and fiber effectiveness of the cloth. The equivalent thickness and modulus (E) are variable functions dependent on loading conditions (magnitude, direction, and biaxial condition). Similarly, the stress (σ) and area moment of inertia (I), which are a function of wall thickness, are also equivalent values.

STRESS SIMILARITY*

The stress state at any point in the actual structure will generally consist of a superposition of pressure stresses, e.g., "hoop stress," and bending and shear stresses resulting from applied loads. The maximum stresses, on which the design is based, will then consist of these two sets of stresses in some proportion which varies from point to point over the structure. To simulate the true distribution of stresses in a subscale test, the parameters must be such that all components of stress in the model act in the same proportions as those in the prototype. The pressure stress, σ_p, in a thin-walled inflatable structure can be expressed by the proportionality

$$\sigma_p \propto \frac{pr_1}{t}, \tag{1}$$

where p is the inflation pressure, r_1 is some radius of curvature and t is the wall thickness (e.g., for a cylinder the hoop stress is pr/t and the axial stress is pr/2t; for a sphere hoop stress is pr/2t). Similarly, the bending stress, σ_b, can be expressed by the proportionality

$$\sigma_b \propto \frac{Mr_2}{I} \tag{2}$$

where M is the bending moment, r_2 is some distance from the neutral axis and I is the area moment of inertia of the cross section. The bending moment, in general, will result from some distribution of loading and can be expressed in terms of the force per unit length, f(x), by the integral

$$M = \int_{x_1}^{x_2} s\, f(x)\, dx, \tag{3}$$

which may be written in terms of the nondimensional length coordinate $\xi = x/\ell$ according to

$$M = \ell^2 \int_{\xi_1}^{\xi_2} \xi\, f(\xi)\, d\xi. \tag{4}$$

By introducing the nondimensional force distribution parameter $\phi(\xi)$ defined as the ratio of the force per unit length at ξ to the value f_o at some value ξ_o, normalized to have the value of unity at $\xi = \xi_o$, the integral of Eq. (4) may be written

*Prepared by Aerospace Research Associates, West Covina, California.

Appendix VII

PRELIMINARY CYLINDER TEST RESULTS

Eqs. (10) and (11) are thus the similarity conditions for invariance of the biaxial stress states from pressure and from bending and for constancy of stress. If the same thickness of fabric is used in the subscale tests, then Eqs. (10) and (11) reduce to

$$\frac{p_{model}}{p_{prototype}} = \frac{F_{prototype}}{F_{model}} = \frac{r_{prototype}}{r_{model}} \tag{12}$$

It can be similarly shown that Eqs. (10) and (11) or Eq. (12) will satisfy the condition of invariance of the ratio of shear stress to pressure stress or shear stress to bending stress. The shear stress, σ_s, may be expressed by the proportionality

$$\sigma_s \propto \frac{Q}{rt}, \tag{13}$$

where the shear force Q is given by

$$Q = \ell f_o \int_{\xi_1}^{\xi_2} \varphi(\xi)\, d\xi, \tag{14}$$

analogous to Eq. (5) for the bending moment. The shear stress then becomes

$$\sigma_s \propto \frac{\ell f_o}{r\,t} \int_{\xi_1}^{\xi_2} \varphi(\xi)\, d\xi \tag{15}$$

and the ratio of the shear stress to the pressure stress, from geometric similarity, with the definition of f_o, may be written

$$\frac{\sigma_s}{\sigma_p} = \frac{F}{p\,\ell^2} \int_{\xi_1}^{\xi_2} \varphi(\xi)\, d\xi \tag{16}$$

With the condition that the force distribution remains invariant, the condition that the stress ratio, Eq. (16), remains invariant gives the similarity law, Eq. (9), which is precisely the condition arrived at from a consideration of the invariance of the ratio of bending stress to pressure stress. There is one final condition which must be satisfied if the subscale tests are to simulate the true strength characteristics of the prototype. This condition requires the invariance of the ratio of the maximum stress to the stress at the point of incipient buckling. The condition must be satisfied to insure that the subscale test component does not buckle before the rupture stress is attained, for example, if such a condition would exist with the prototype. The state of incipient

buckling occurs when the bending stress in a particular direction of the membrane is just equal and opposite the pressure stress. Since this condition involves the ratio of the bending stress to the pressure stress, which was assumed invariant in deriving the similarity laws, the condition is automatically satisfied in the scaling laws derived above.

DEFLECTION SIMILARITY

The differential equation for transverse deflections of a beam having an area moment of inertia I(x) and Young's modulus E is

$$\omega''(x) = \frac{M(x)}{EI(x)} \tag{17}$$

By introducing, as before, the nondimensional length parameter ξ, the deflection equation may be written

$$\omega''(\xi) = \frac{\ell^2 M(\xi)}{EI(\xi)} \tag{18}$$

which, using Eq. (5) for the moment $M(\xi)$, becomes

$$\omega''(\xi) = \frac{\ell^4 f_o}{EI(\xi)} \int_{\xi_1}^{\xi_2} \xi\varphi(\xi)\, d\xi \tag{19}$$

The moment of inertia may be expressed in terms of the moment of inertia I_o at some value ξ_o, multiplied by the function $\iota(\xi)$, which is the ratio of the moment of inertia at ξ to the value at ξ_o, normalized to have the value of unity at ξ_o. Introducing a nondimensional deflection parameter, $\eta(\xi)$, defined as the ratio of the deflection $\omega(\xi)$ to some dimension ℓ, the deflection equation, Eq. (19), becomes

$$\eta''(\xi) = \frac{\ell^2 F}{EI_o \iota(\xi)} \int_{\xi_1}^{\xi_2} \xi\varphi(\xi)\, d\xi = \psi \frac{\int_{\xi_1}^{\xi_2} \xi\varphi(\xi)\, d\xi}{\iota(\xi)} \tag{20}$$

where ψ is a nondimensional parameter defined by

$$\psi = \frac{\ell^2 F}{EI_o} \tag{21}$$

If the force distribution $\varphi(\xi)$ remains invariant and geometric similarity is maintained, then $\iota(\xi)$ will be invariant and the similarity law for deflection becomes

$$\left(\frac{\ell^2 F}{EI_o}\right)_{model} = \left(\frac{\ell^2 F}{EI_o}\right)_{prototype} \tag{22}$$

Since I_o is proportional to $\ell^3 t$, the similarity law may be written

$$\left(\frac{F}{E\ell t}\right)_{model} = \left(\frac{F}{E\ell t}\right)_{prototype} \tag{23}$$

If the model is constructed of the same material as the prototype with the same wall thickness, the similarity law reduced to

$$\frac{F_{model}}{F_{prototype}} = \frac{\ell_{model}}{\ell_{prototype}} \tag{24}$$

which states that deflections will vary directly as the size of the model*, provided the applied loads are scaled accordingly.

VIBRATION SIMILARITY

The equation of motion for transverse vibrations of a beam is

$$\left[EI(x)\omega''(x,t)\right]'' + m(x)\,\ddot{\omega}(x,t) = 0, \tag{25}$$

where m(x) is the mass per unit length at position x. The prime denotes differentiation with respect to x and the dot denotes differentiation with respect to t. For sinusoidal motion,

$$\omega(x,t) = W(x)\sin \omega t, \tag{26}$$

which gives, for the equation of motion,

$$\left[EI(x)\,W''(x)\right]'' - \omega^2\, m(x)\, W(x) = 0. \tag{27}$$

The quantities m(x) and I(x) may be expressed in terms of nondimensional parameters according to

$$\left.\begin{aligned} m(x) &= m_o\,\mu(x) \\ W(x) &= W_o\,\eta(x) \\ I(x) &= I_o\,\iota(x) \end{aligned}\right\} \tag{28}$$

*Similarly, shear deflections, if significant, may be shown to vary directly.

where the nondimensional quantities $\mu(x)$, $\eta(x)$ and $\iota(x)$ are distributions of mass, deflection and moment of inertia normalized to have the value of unity at $x = 0$. In terms of these parameters Eq. (27) becomes

$$\left[EI_o\, \iota(x)\, \eta''(x)\right]'' - \omega^2 m_o\, \mu(x)\, \eta(x) = 0. \tag{29}$$

By introducing, as before, the dimensionless length variable ξ, Eq. (29) becomes

$$\left[\iota(\xi)\, \eta''(\xi)\right]'' - \Omega^2 \mu(\xi)\, \eta(\xi) = 0, \tag{30}$$

where Ω^2 is a nondimensional frequency parameter defined by

$$\Omega^2 \equiv \frac{\ell^4 \omega^2 m_o}{EI_o} \tag{31}$$

and the primes now denote differentiation with respect to ξ. Eq. (30) is the differential equation for transverse vibrations of a beam expressed entirely in terms of nondimensional parameters. Solution of this equation will yield the mode shapes $\eta(\xi)$ in terms of the nondimensional frequency parameter Ω. Hence, any model with the correct distributions of mass, $\mu(\xi)$ and the moment of inertia, $\iota(\xi)$, will yield the same mode shapes as the prototype, but the natural frequencies will differ, in general, from those of the prototype according to the magnitudes of the physical parameters in the nondimensional frequency parameter Ω. For example, a geometrically similar model of an inflatable structure will have natural frequencies compared with those of the prototype according to

$$\frac{\omega^2_{\text{model}}}{\omega^2_{\text{prototype}}} = \left(\frac{EI_o}{m_o \ell^4}\right)_{\text{model}} \left(\frac{m_o \ell^4}{EI_o}\right)_{\text{prototype}} \tag{32}$$

The moment of inertia is proportional to $r^3 t$ and the mass per unit length is proportional to $\rho r t$, where ρ is the mass density of the material and r is some average radius. With the condition of geometric similarity, the frequency ratio becomes

$$\frac{\omega^2_{\text{model}}}{\omega^2_{\text{prototype}}} = \left(\frac{E}{\rho r^2}\right)_{\text{model}} \left(\frac{\rho r^2}{E}\right)_{\text{prototype}} \tag{33}$$

which, for a model constructed of the same material as the prototype, reduces to

$$\frac{\omega^2_{model}}{\omega^2_{prototype}} = \frac{r^2_{prototype}}{r^2_{model}} \tag{34}$$

Hence, for the scaling described above, the mode shapes of the model will be the same as those of the prototype, whereas the frequencies will vary inversely as the size of the structure.

Appendix VII

PRELIMINARY CYLINDER TEST RESULTS

30.335.7.5

SPACE-GENERAL CORPORATION
[illegible] EAST FLAIR DRIVE • EL MONTE, CALIFORNIA • [illegible]
A SUBSIDIARY OF AEROJET-GENERAL CORPORATION

ENGINEERING TEST SUMMARY

Report No. 1034-A

PROGRESS ☐ FINAL ☒

P.S. NO.:
JOB NO.: 335
DATE: 5-27-64

TO: S. L. Tomkinson

COPIES:
Dr. R. F. Brodsky
Dr. M. Eimer
G. H. Fredy
J. F. Keville (3)
C. B. Linnecke
A. Speyer
A. H. Olson
H. Wright
ELD File

TYPE OF PLANNING SHEET: Cylinder Test Requirement - Project First

S.G.C. DWG. NO.	MFRS DWG NO.	MODEL NO.	SERIAL NO.
335SK3	335SK3	-5	1

MFR OF SPECIMEN	CITY	STATE
SGC	El Monte	Calif.

FUNCTION OF PART: Test Specimen

FOR INSTALLATION IN: 335-1034 Test Fixture

TYPE OF TEST	START TEST (DATE)	END TEST (DATE)
Load Deflection	3-9-64	3-10-64

TEST ENGINEER	SUPERVISOR	COMPREHENSIVE REPORT FOLLOWS
C. B. Linnecke	G. H. Fredy	YES ☐ NO ☒

UNIT	ZONE	EXT	REFERENCES:
5150	SEF	1813	Test Requirement Revision A - Project First

OBJECT

The object of this test was to determine the characteristics of metal cloth cylinder when subjected to internal pressures and externally applied loads at room temperature.

SPECIMEN(S)

1. One (1) 7" diameter tensil bolting cloth cylinder 335SK3-5, S/N 1
2. One (1) latex rubber liner

DISPOSITION OF SPEC. ENGR.:

Burst and delivered to Project.

TEST EQUIPMENT AND IDENTIFICATION

1. Loading fixture No. 335-1034 made up for applying loads to Project First metal cloth cylinders.
2. One inch displacement .001 dial indicators.
3. Mercury manometer calibrated in 1/10 psi.

SGC [illegible]

TEST SETUP

Test was set-up to apply shear, bending, and torsional loads with various internal pressure to the 7" diameter metal cloth cylinder.

TESTING PERFORMED

1. Preliminary shear, torsion, and bending tests were run according to the test requirement for the 7" diameter cylinder. Rough data of these tests are presented as an appendix of this report.*

2. Shear, bending, and torsional loads were then applied as requested in Revision A of the 7" diameter Cylinder Test Requirement. Prior to this test the seams of the specimen were re-welded to insure against a weld failure, and to fix a small separation of the weld which occurred during the preliminary test. Displacement and rotational curves as shown in Figure 1 through 9 are called out as noted in Test Requirement Revision A. See Figures 10 and 11 for instrumentation and load application locations.

3. Pressure was then increased with no external loads applied until burst occurred. Diameter versus pressure increase is shown on Table 1. To insure against premature failure of the seam, a strip of fiberglass tape was wrapped around the cylinder in an area where the seam had started to tear out at the weld points. No further weld failures occurred.

CONCLUSIONS

1. The cylinder burst at an internal pressure of 16.5 psig.

2. Due to leak in the internal rubber bladder, pressures at which the tests were run could have been as much as 5% lower than indicated.

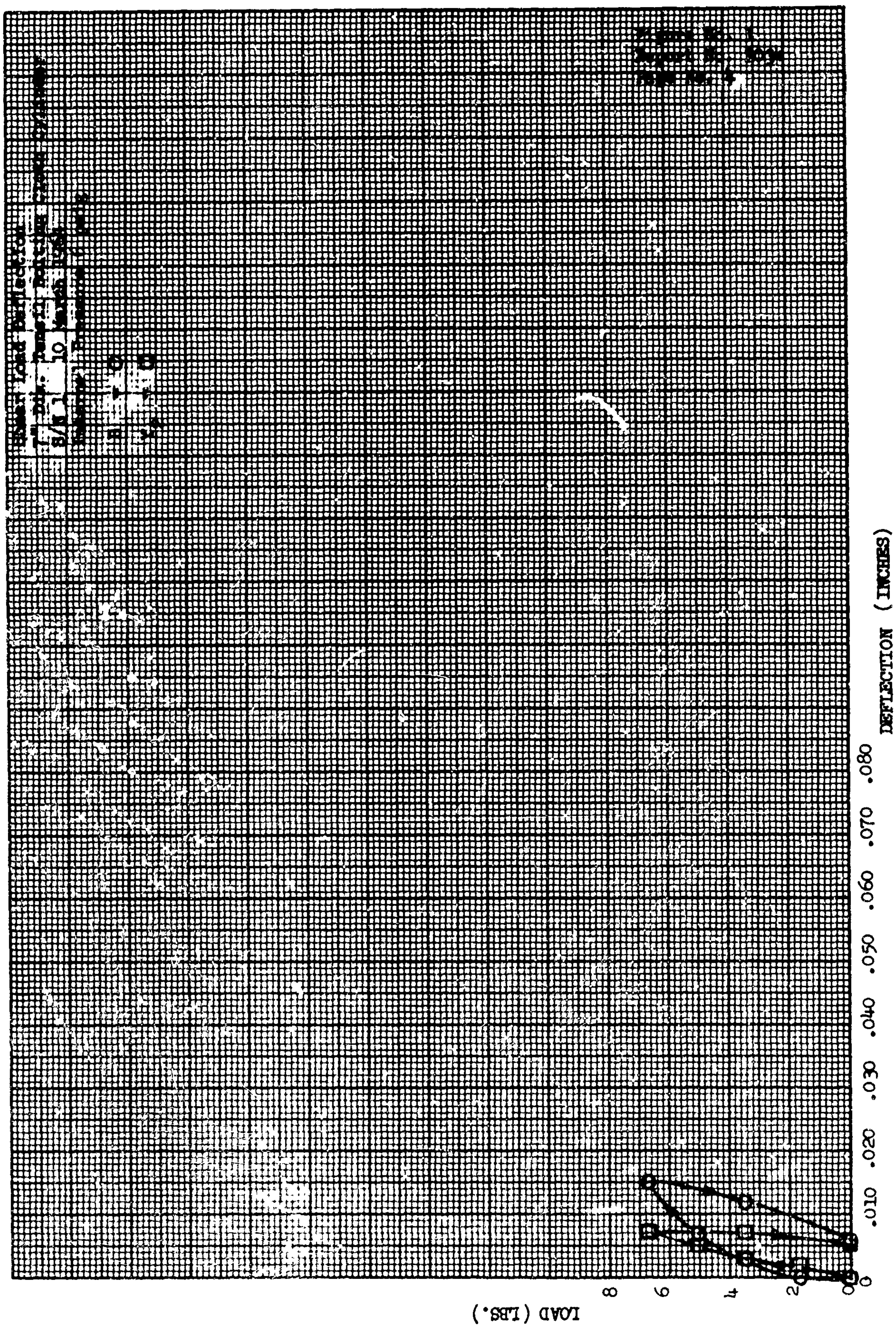
---

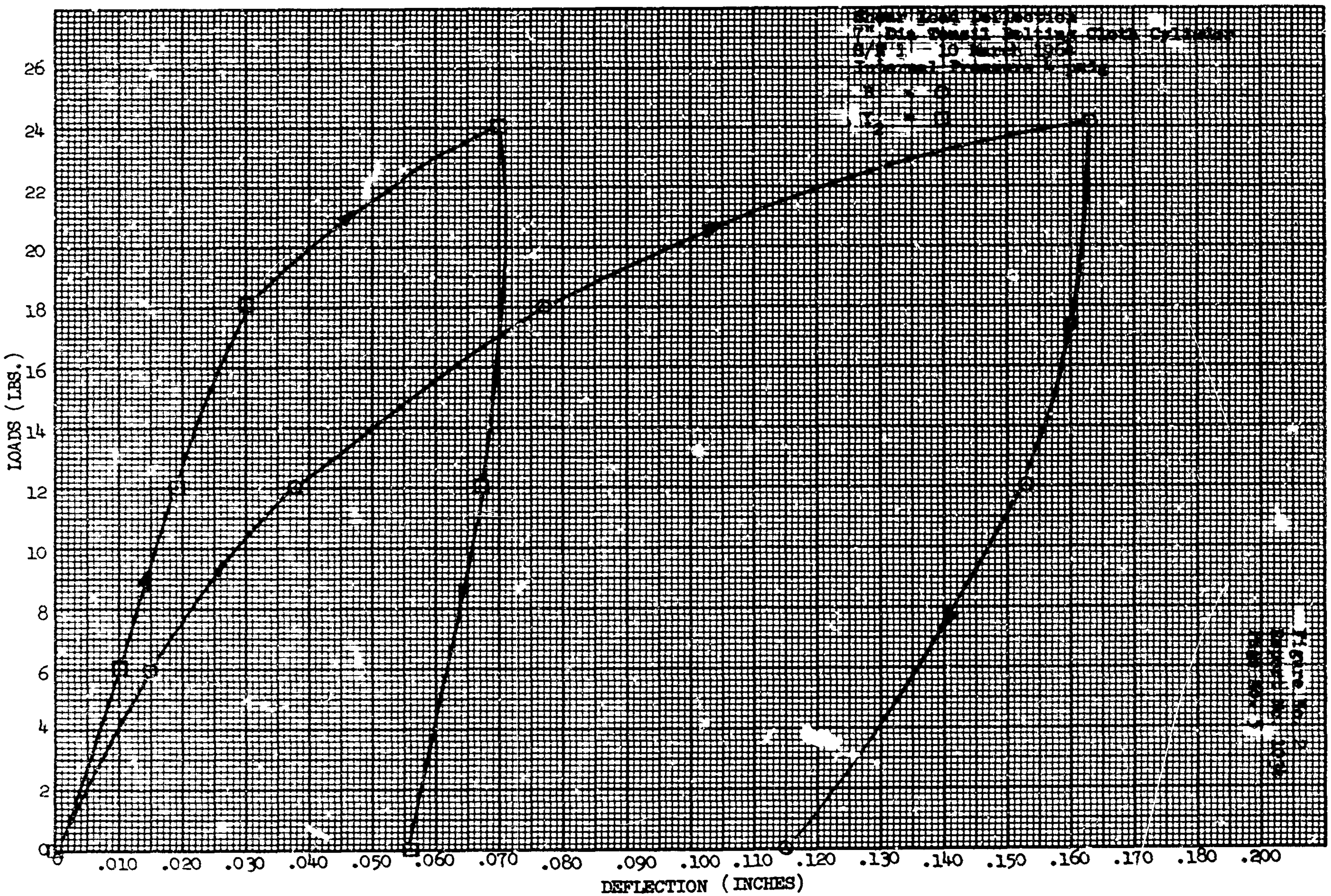
* Available in Space-General project files - not included in this report.

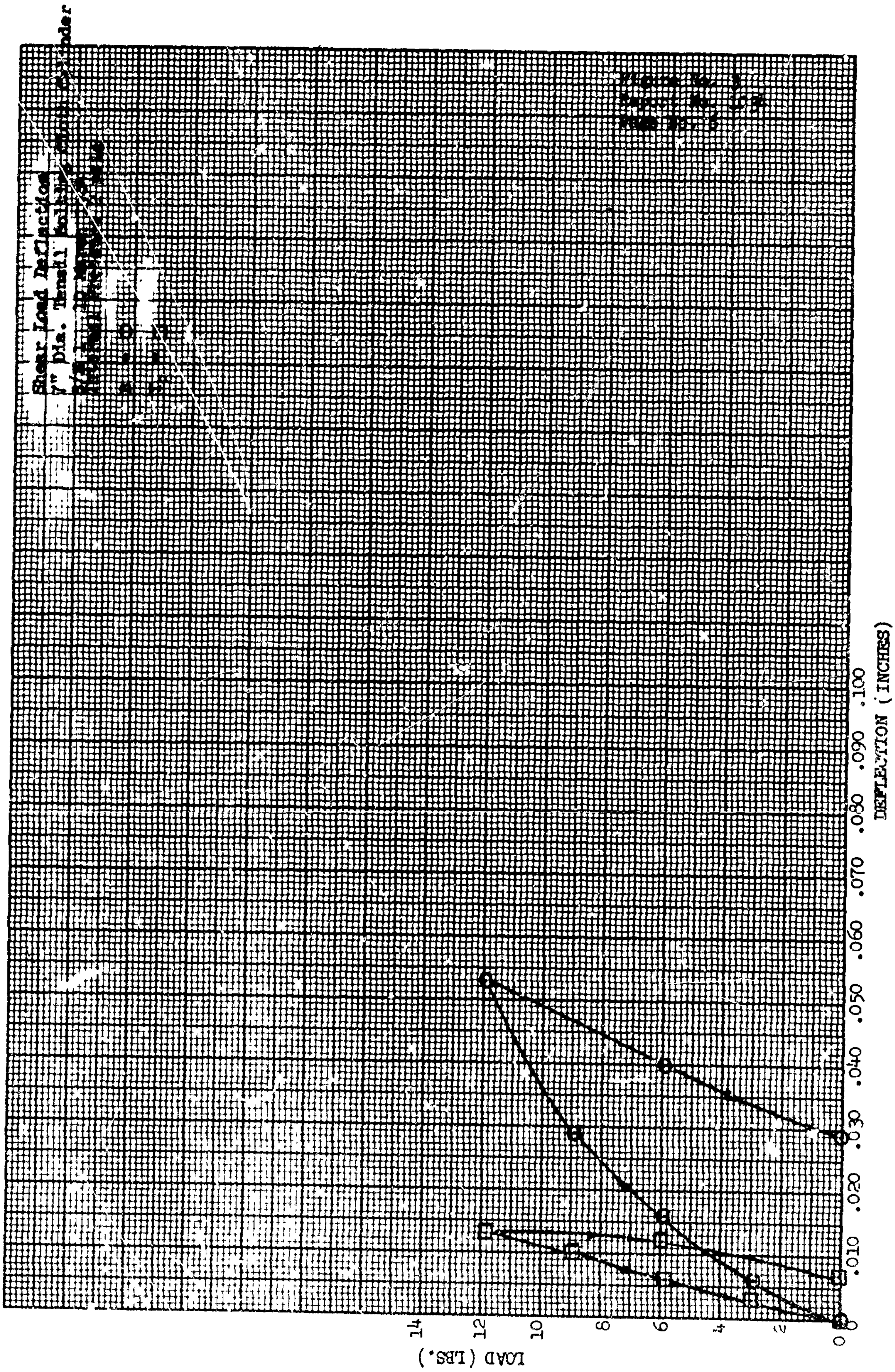
TABLE I

Diameter Versus Internal Pressure

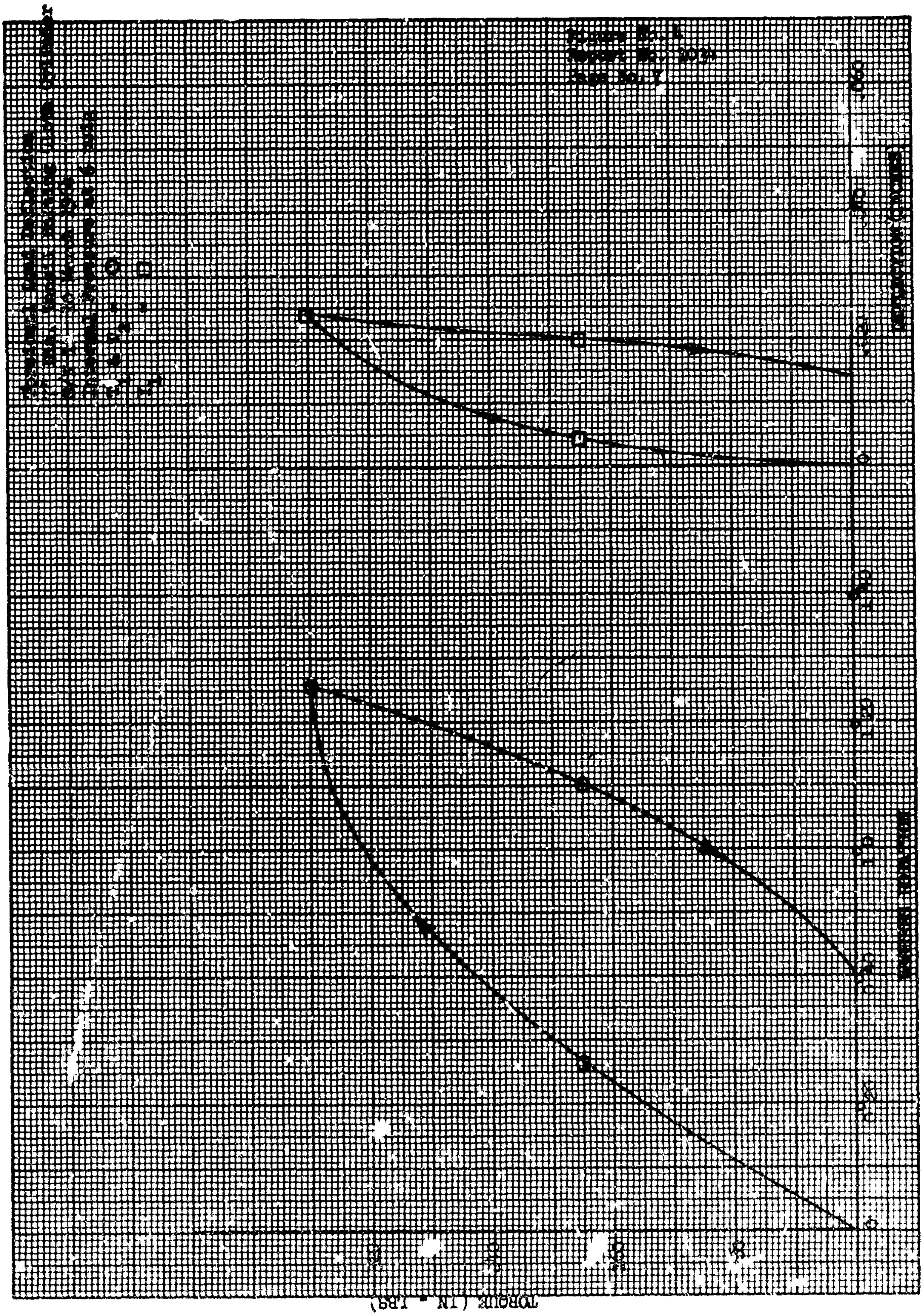
Pressure (psig)	Diameter (Inches)
2.0	7.049
4.0	7.055
6.0	7.061
7.0	7.063
8.0	7.065
9.0	7.065


DEFLECTION (INCHES)
LOAD (LBS.)
0
.010
.020
.030
.040
.050
.060
.070
.080
0
2
4
6
8

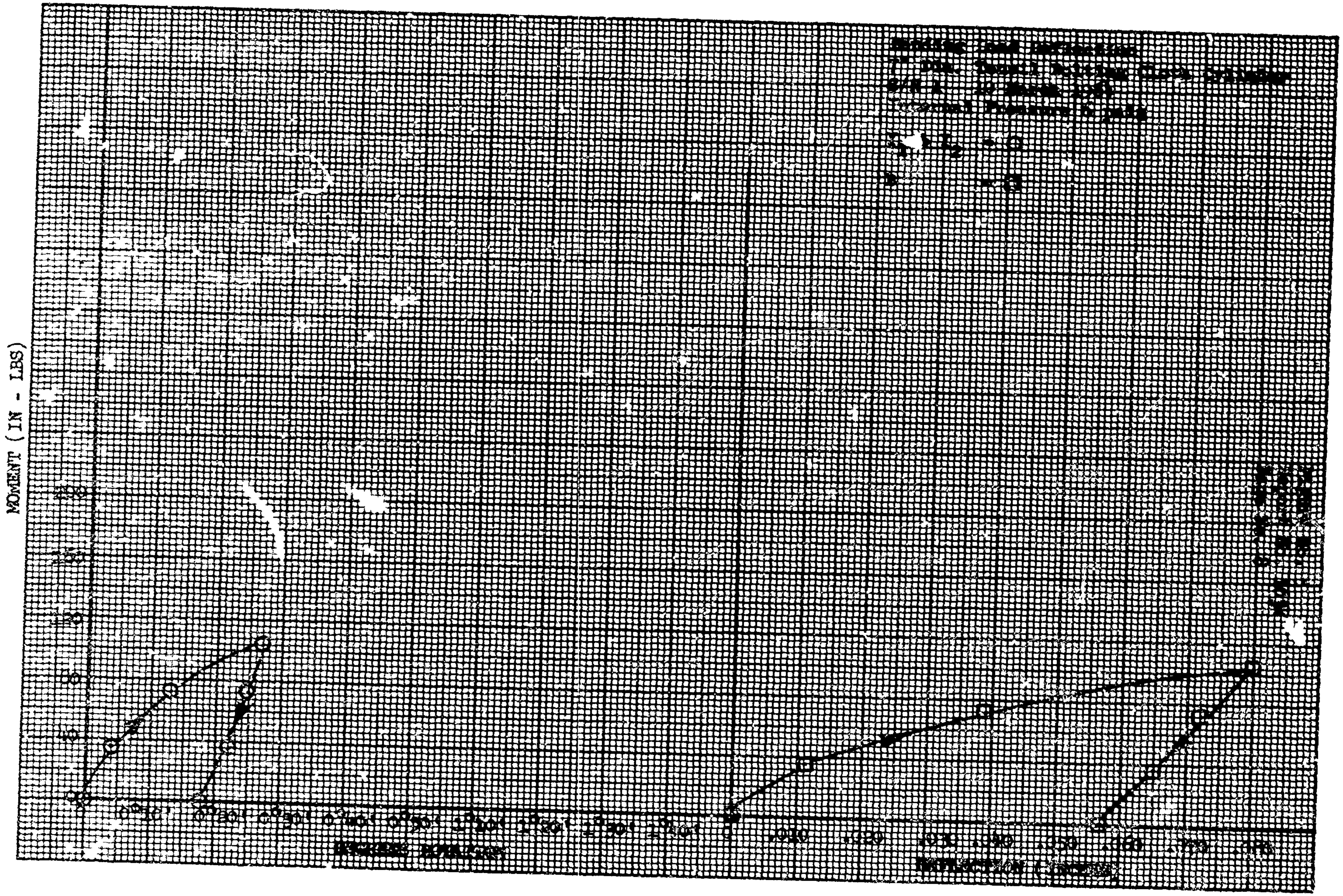

LOADS (LBS.)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
.010
.020
.030
.040
.050
.060
.070
.080
.090
.100
.110
.120
.130
.140
.150
.160
.170
.180
.200
DEFLECTION (INCHES)

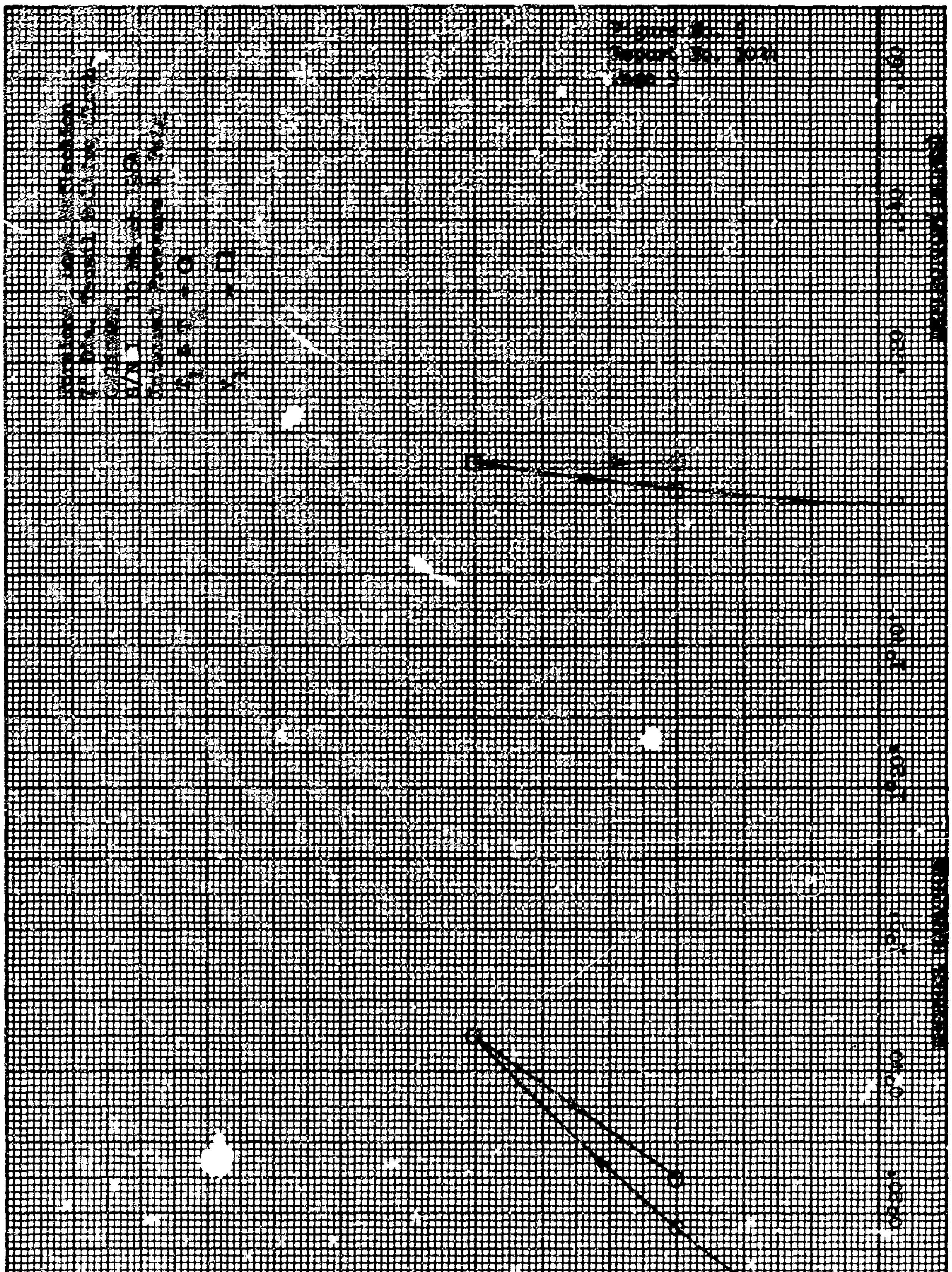


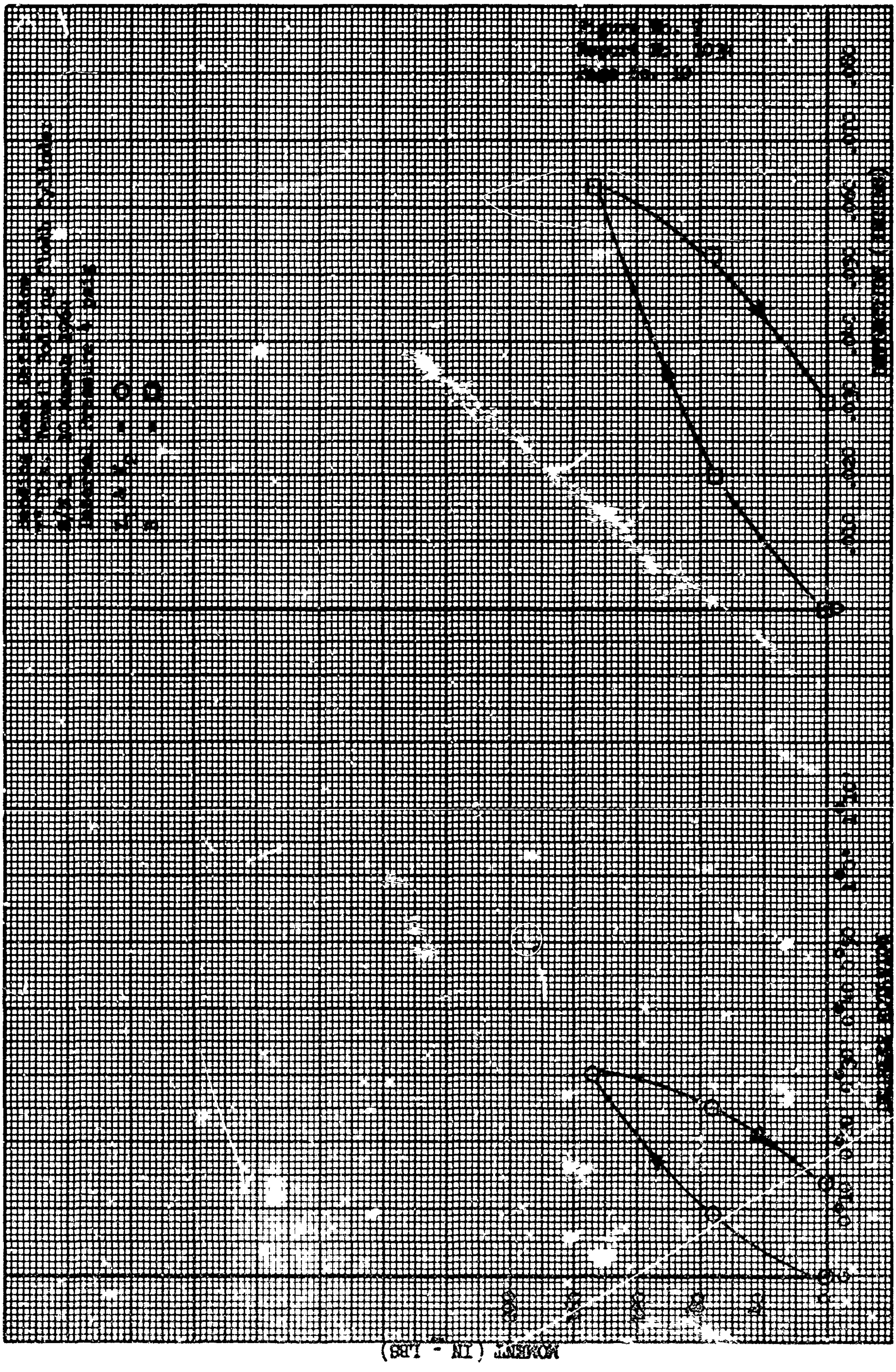
Shear Load Deflection
DEFLECTION (INCHES)
LOAD (LBS.)

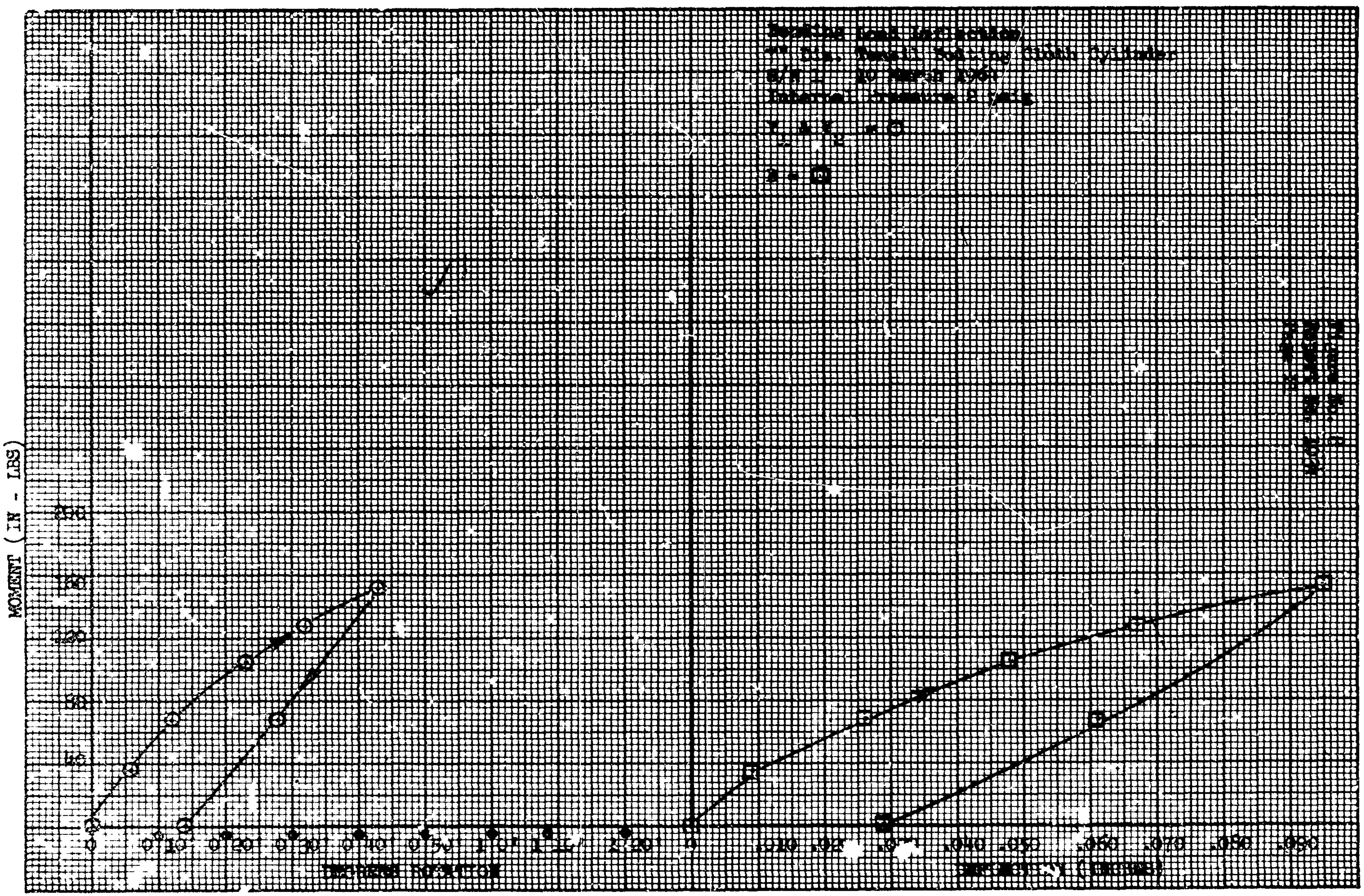


TORQUE (IN - LBS)


MOMENT (IN - LBS)




MOMENT (IN - LBS)


MOMENT (IN - LBS)
Bending Load Deflection
Internal Pressure
0
.010
.040
.050
.060
.070
.080
.090

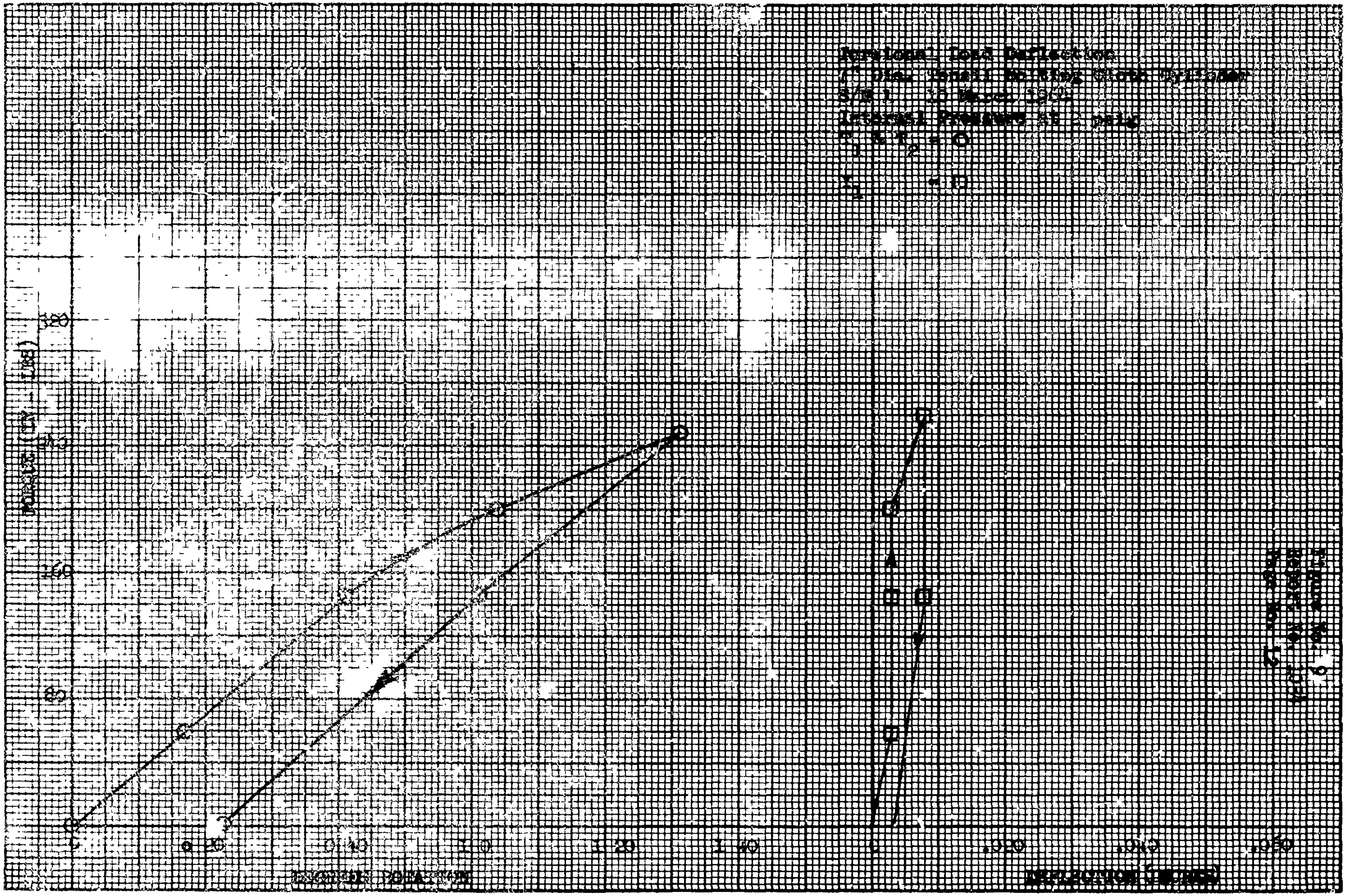
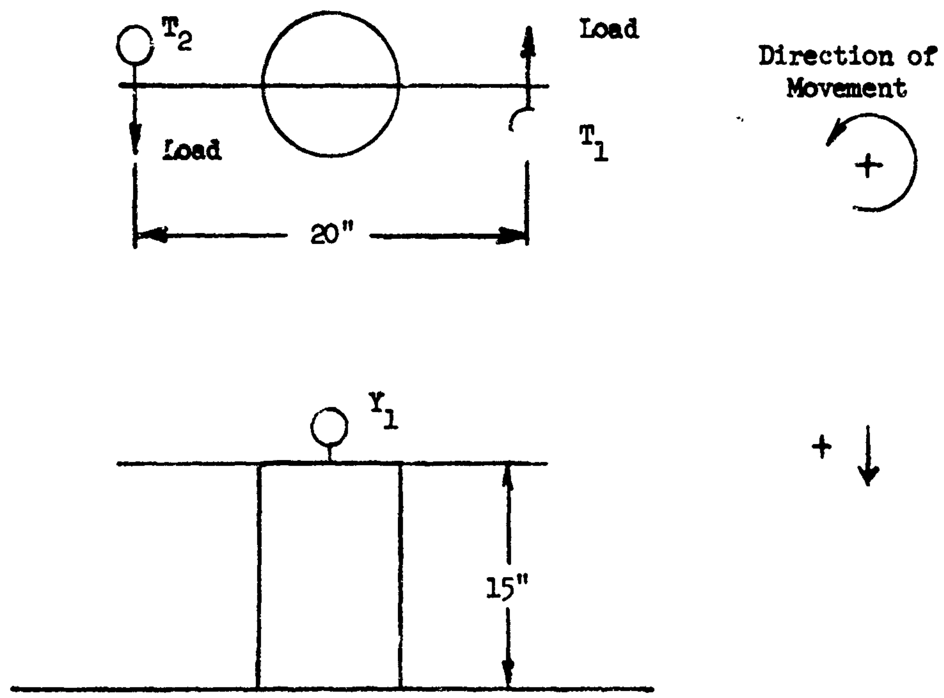

Torsional Load Deflection
S/N 1 10 March 1962
Internal Pressure at 2 psig
T_1 & T_2 = ○
T_1 = □
Figure No. 9
Page No. 12
0
.20
.40
.60
.80
1.00
1.20
1.40
.010
.020
.030
40
80
120
160
DEGREES ROTATION
DEFLECTION (INCHES)

FIGURE 10

TORSION DIAL INDICATOR LOCATIONS



SHEAR DIAL INDICATOR LOCATIONS

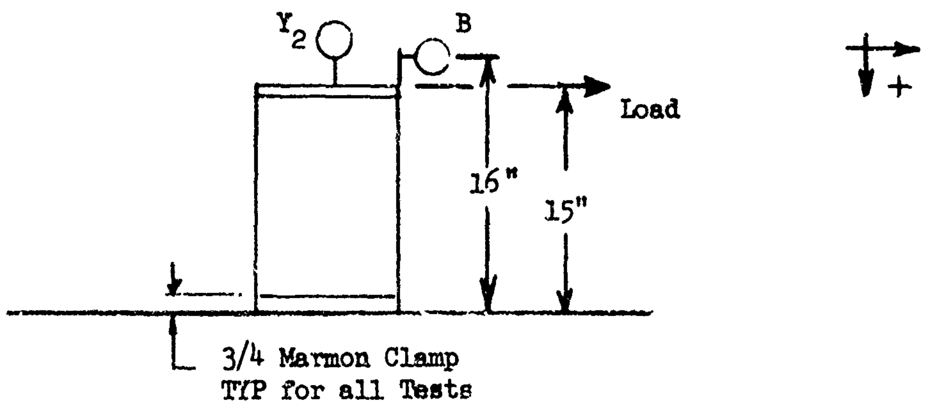
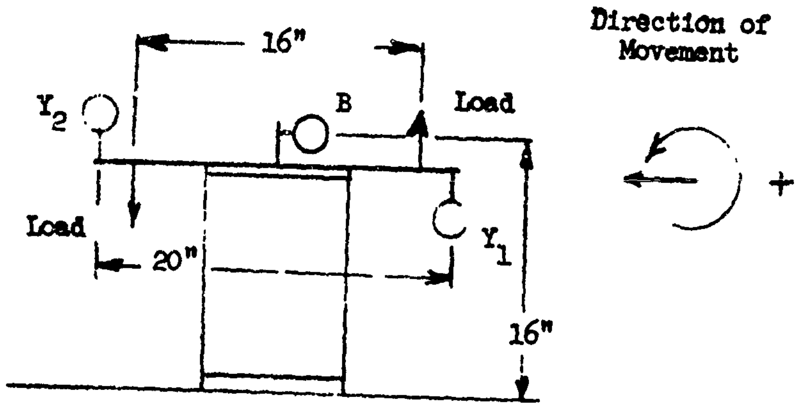


FIGURE 11

BENDING DIAL INDICATOR LOCATIONS



Appendix VIII

STRUCTURAL ANALYSIS AND EVALUATION OF UNCOATED AND COATED 7-INCH DIAMETER CYLINDERS

Appendix VIII

STRUCTURAL ANALYSIS AND EVALUATION OF UNCOATED AND COATED 7-INCH DIAMETER CYLINDERS

I. TEST LOADS ANALYSIS

A. Cylinder Test Loads

Torsion, shear, and bending moment loads were derived for the static load/deflection test of the uncoated bias-ply, the uncoated cross-ply, and the coated two-ply cylinders (7 inches in diameter and 15 inches in length). These loads were calculated as concentrated couples for separate application through a test fixture attached to the forward face of the cylinder. Maximum static loads for each mode were determined on the basis that the fabric membrane loads due to internal pressure would just balance the externally applied compressive membrane loads; in other words, the point of incipient fabric buckling. Assuming a design pressure of 11 psi for a 32-inch-diameter two-ply cylinder, the test pressure for the two-ply 7-inch-diameter cylinder was increased to 50 psi by the ratio of the diameters to simulate the design membrane stress level in these smaller test cylinders. Considering the fabric strength capability of the individual ply fabric, the two-ply test pressure was reduced to 36 psi for the cross-ply cylinder and 14.3 psi for the bias-ply cylinder. Based on these pressures, the maximum test loads were determined by the following isotropic membrane formulas for incipient buckling:

$$M = \frac{\pi R^3 p}{2} \quad \text{(moment)} \qquad (1)$$

$$V = \frac{M}{2R} \quad \text{(shear)} \qquad (2)$$

$$T = \frac{2\pi R^3 p}{\sqrt{2}} \quad \text{(torsion)} \qquad (3)$$

where: R = radius (in.) and p = pressure (psi).

The above formulas apply to the cross-ply and two-ply cylinders only. For the bias-ply, the following formulas for orthotropic fabrics are applicable:

$$f_\alpha = f_x \cos^2 \theta + f_y \sin^2 \theta + 2 f_{xy} \sin \theta \cos \theta \qquad (4)$$

$$f_\beta = f_x \sin^2 \theta + f_y \cos^2 \theta - 2 f_{xy} \sin \theta \cos \theta \qquad (5)$$

where: f_α = stress in warp direction

f_β = stress in fill direction

f_x = meridional stress

f_y = hoop stress

f_{xy} = applied shear stress

θ = angle between applied stress and fabric stress.

Using the above formulas and the given maximum pressure, the loads necessary to cause incipient buckling for each type of cylinder were calculated to be as follows:

(1) Bias-ply cylinder (uncoated)

p = 14.3 psi (given)

M = 2892 in.-lb.

V = 207 lb

T = 1020 in.-lb.

(2) Cross-ply cylinder (uncoated)

p = 36 psi (given)

M = 2420 in.-lb.

V = 173 lb

T = 6850 in.-lb.

(3) Two-ply cylinder (coated)

p = 50 psi (given)

M = 3380 in.-lb.

V = 241 lb

T = 9530 in.-lb.

To account for the difference between membrane theory and orthotropic fabric theory of the bias-ply, the moment, shear, and torque values for the two-ply coated cylinders were changed to the following:

$p = 50$ psi

$M = 3630$ in.-lb.

$V = 207$ lb

$T = 1530$ in.-lb.

The above loads were considered as 100% test loads and were used as the basis of applying load increments.

B. Coated Frustum Test Loads

The coated two-ply frustums (10-inch maximum diameter and 30-inch length) were fabricated with the same taper (21:1) as the proposed paraglider booms. Assuming the frustum to be a sub-scale specimen of the forward end of the boom, the test loads were determined from the limit loads at the boom forward section. Since the fabric of the test specimen and full-scale boom is identical, the membrane loads in the test specimen and boom should be equal (i.e., $q_{specimen} = q_{boom}$). Membrane loads due to bending moment, body shear, and torsion may be determined from the following formulas:

$$q_M = M/\pi R^2 \tag{6}$$

$$q_V = \frac{V \sin \theta}{\pi R} = \frac{V}{\pi R} \quad \text{(at neutral axis)} \tag{7}$$

$$q_T = T/2\pi R^2 \tag{8}$$

By equating the specimen membrane loads to the boom limit membrane loads, the test loads may be calculated from the following formulas:

$$M_{10} = M_{32} \left(\frac{R_{10}}{R_{32}}\right)^2 \tag{9}$$

$$V_{10} = V_{32} \left(\frac{R_{10}}{R_{32}}\right) \tag{10}$$

$$T_{10} = T_{32} \left(\frac{R_{10}}{R_{32}}\right)^2 \tag{11}$$

The limit loads of the boom were derived from the aerodynamic loads presented in Section 3.2. The combined limit loads at the boom-to-apex junction used in these calculations are as follows:

V_B = 405 lb (shear)

M_B = 48,400 in.-lb. (bending moment)

T_B = 3,520 in.-lb. (torsion)

It will be noted that these loads are greater than those presented in Section 3.2.4. The data in this appendix were generated earlier in the program using more conservative conditions. Therefore the test limit loads will tend to be higher than actual flight loads predicted by later, more rigorous calculations.

At a boom station equivalent to the small end of the frustums, the boom combined limit load were determined to be the following:

V'_B = 267 lb

M'_B = 17,400 in.-lb.

Using these limit loads and the above formulas (9, 10, 11), the following frustum test loads were obtained:

(1) At base of frustum (large end)

V_T = 126.5 lb

M_T = 4710 in.-lb.

T_T = 344 in.-lb.

(2) At small end of frustum

V'_T = 83 lb

M'_T = 1690 lb

These test loads (100%) were used to determine the concentrated loads applied to the test jig.

II. STATIC TEST RESULTS

A. Uncoated Cylinders

The bias-ply and cross-ply uncoated cylinders were tested separately using an internal thin rubber bladder (as described in Section 3.11.3.1). The internal pressure was increased in several equal increments up to design pressure. At each pressure level, the bending moment was applied in equal increments of the calculated incipient buckling moment until actual buckling occurred. The bending moment was then released in the same increments until all of the applied load was released. Lateral displacement, angle of twist, and the bending slope were recorded after each increment. The following loads and results were obtained for the bias-ply cylinder.

Seven-Inch-Diameter Bias-Ply Cylinder Test Results

Internal Pressure (psi)	Bending Moment Increment (in.-lb)	Buckling Bend. Mom. (in.-lb)	Calculated Bend. Mom. (in.-lb)	Percent of Calc.	Total Deflection	
					Rotation (deg)	Translation (in.)
5	253	758	1010	75	18.0	2.75
10	505	1515	2020	75	19.8	2.59
14.3	723	2169	2892	75	21.6	2.88

The bias-ply cylinder increased 0.786 inch at the mid-diameter and shortened 0.45 inch in length during the bending test. As indicated in the table above, large deflections and rotations occurred. At the recorded buckling moment, the cylinder actually bulged over the cuff at the lower attachment Marman strap as shown in Figure 206 of Section 3.11.3.1.

A review of the changes in geometry of the bias fiber explains the reasons for the large lateral deflection, bending slope, and the bulging mode of buckling. Figure A represents the fiber orientation prior to loading.

During pressurization, the hoop membrane load is twice the axial membrane load; therefore, the 45° bias fibers reorient as shown in Figure B. The magnitude would be as indicated above, except for the resistance offered by the crimp of the weave which offered significant restraint that reduced values to those obtained during the actual static tests. The bending moment adds to the membrane load on the tension side of the cylinder and reduces the pressure tension load on the compressive side. At the same time, the pressure hoop stress realigns the fibers again. Figures C and D indicate these changes.

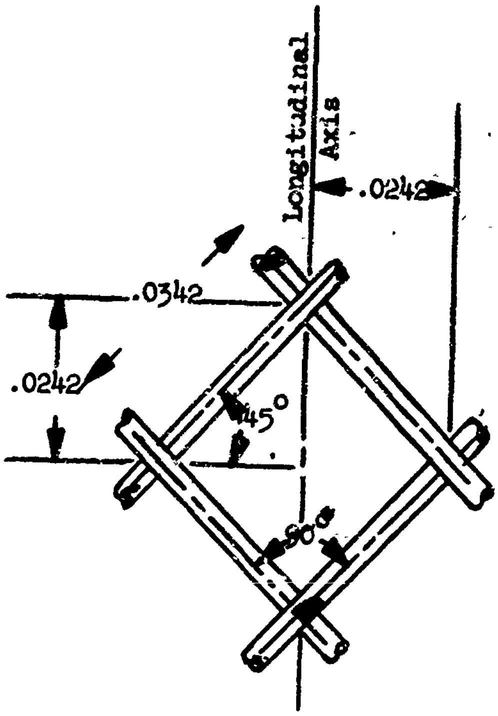


FIGURE A

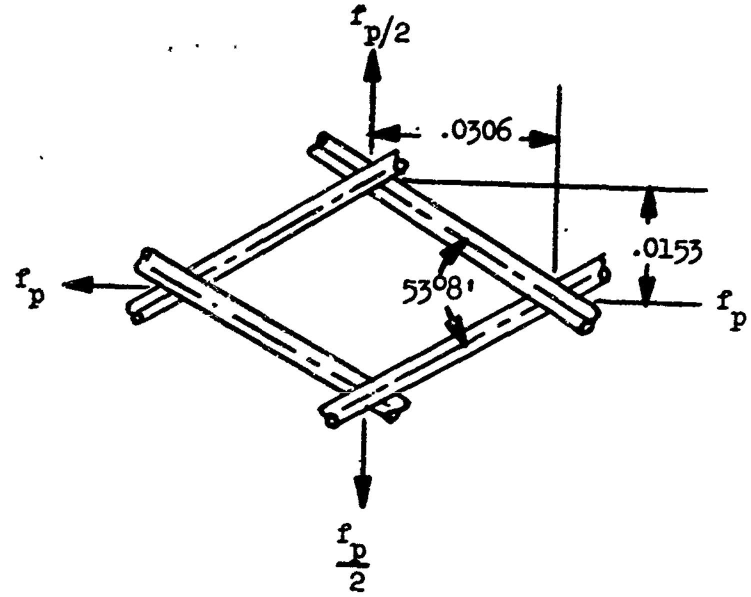


FIGURE B

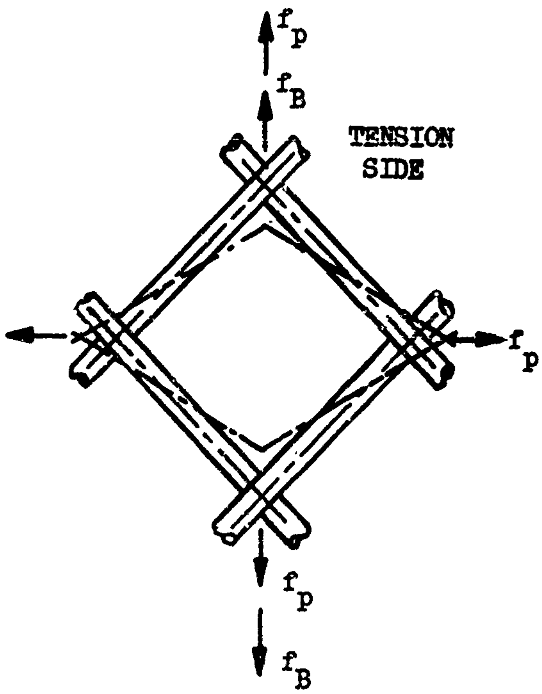


FIGURE C

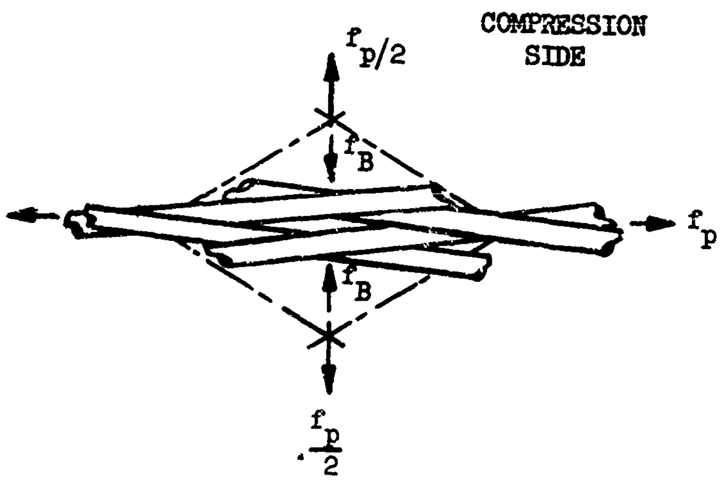


FIGURE D

The phantom lines indicate the pressured condition, and the solid lines show the new position. It can be seen that the tension side tends to stiffen (bulge less than during pressurization), and the compression side tends to bulge more. Figure 205 of Section 3.11.3.1 shows the original bulging during pressurization, and Figures 206 and 207 illustrate the above effects under bending loads.

Calculations for obtaining the bending moment that would cause incipient buckling (i.e., bending moment where the bending compressive load equals the axial tension load due to pressurization) did not account for these changes in fiber orientation or the effect of the crimp. They were intended only as a guide for designing test fixtures and selecting load increments. By consistently achieving 75% of the calculated ideal incipient buckling bending moment, a fair measure of these effects has been determined for the uncoated bias-ply subjected to bending moments.

After the bending test was completed, the bias-ply cylinder was subjected to an internal pressure of 14.3 psi. Then, a lateral shear load of 207 pounds (100%) was applied in 51.8-pound increments at the forward end of the cylinder, resulting in a 25° slope and a 4.20-inch deflection at maximum load. The cylinder again bulged over the base Marmon strap cuff (as shown in Figure 207 of Section 3.11.3.1). However, the shear load that caused initial buckling was not recorded. It should be noted that a total deflection of 2.88 inches was obtained during the bending test and 4.20 inches during the shear test of the same cylinder for the same internal pressure and bending moment. The concentrated lateral load induces both bending and shear stresses in the cylinder. A comparison of Figures 206 and 207 shows the similarity in the shape of the cylinder under pure banding moment and lateral shear, respectively. However, the greater lateral displacement recorded during the shear test can easily be seen. Figure 206 has the classical curved cylindrical shape due to pure bending, whereas Figure 207 has the combined curved shape plus the lateral shear displacement. The shear test clearly illustrates the effect of combined bending deflection and lateral shear displacement due to the combined loads.

Upon removal of the load, a torque of 1020 inch-pounds was applied in 255 inch-pound increments. The resulting angle of twist was 2.9°, and no buckles were perceptible in Figure 208, Section 3.11.3.1. The torque was removed and then increased to 2040 inch-pounds (i.e., twice the calculated buckling torque), at which time the cylinder slipped on the mounting jig. The weave characteristics of the bias-ply prevents the possibility of noticeable buckling waves to occur even though some of the fibers are undoubtedly in compression. The diagonal fibers in tension will tend to straighten out and will preload or crimp torsionally unloaded opposite diagonal fibers, thus preventing any noticeable slack.

The uncoated cross-ply cylinder was tested in the same manner. The following loads and results were obtained for the cross-ply cylinder.

Seven-Inch-Diameter Cross-Ply Cylinder Test Results

Internal Pressure (psi)	Bending Moment Increment (in.-lb)	Buckling Bend. Mom. (in.-lb)	Calculated Bend. Mom. (in.-lb)	Percent of Calc.	Total Deflection	
					Rotation (deg)	Translation (in.)
12	201	1207	807	150	.28	.35
24	403	2421	1614	150	.56	.53
36	1000	1750 (failure)	2420	72	-	-

Premature failure of the cross-ply cylinder prevented the completion of the lateral shear and torsional tests. The severe clamp loads, required for attaching and sealing the specimen to the mounting fixture, combined locally with the applied pressure and bending loads to cause failure. Inspection of the failed specimen indicated that some of the fibers had been deformed under the clamp. However, results obtained during the bending test were quite significant.

Since the fibers of the cross-ply cylinder are oriented in the direction of the pressure membrane loads, the cylinder did not bulge during pressurization, but remained straight and firm. The longitudinal orientation of the cross-ply fibers are in the same direction as the bending moment membrane loads. As indicated in the tables above, the bending rotation and lateral displacement were extremely low for the cross-ply cylinder when compared to the bias-ply cylinder. This is attributed to the fact that the cross-ply cylinder displacements are the results of the strain in the individual fibers and the stretching of the crimp, whereas the bias-ply cylinder includes these effects plus the large displacements resulting from the realignment of the fibers.

The efficiency of the cross-ply cylinder to carry bending moments was verified by its consistent ability to withstand 150% of the calculated bending moment for incipient buckling when the bending compressive load is just equal and opposite to the pressure tension load. This additional compressive load-carrying capability is attributed to the individual compressive and bending strength of the longitudinal fibers which are supported by the lateral fibers under hoop stress. Had it been performed, the torsional test of the cross-ply cylinder, undoubtedly would have demonstrated the inefficiency of the cross-ply under torsion due to the necessary realignment of the fibers to carry the torsional shear loads. However, the test of the two-ply coated cylinder (reviewed below) demonstrated the excellent rigidity and structural integrity of cross-ply and bias-ply cylinders bonded together to react all three modes of loading: bending, lateral shear, and torsion.

B. Coated Two-Ply Cylinder

The test setup for the coated two-ply cylinder was similar to that employed in the previous tests of the individual uncoated single-ply cylinders. Bending, shear, and torsion loads were applied separately in equal increments up to the calculated incipient buckling loads. When buckling was not observed at these loads, the maximum loads were maintained and the pressure was reduced until buckles in the specimen were noted.

The following loads and results were obtained for the coated two-ply cylinder:

Seven-Inch-Diameter, Coated Two-Ply Cylinder Test Results

Type of Load	Internal Pressure (psig)	Applied Max. Static Load	Total Deflection		Buckling Pressure at Max. Load (psig)	Percent of Pressure
			Translation (in.)	Rotation (deg)		
Bending	16.6	1210 in.-lb	.342	2.1	5.5	33
Bending	33.0	2420 in.-lb	.567	3.8	25.0	75
Bending	50.0	3630 in.-lb	.750	5.4	28.0	56
Shear	50.0	207 lb	.311	1.1	25.0	50
Torsion	50.0	1530 in.-lb	--	1.9	--	

The rotation obtained during the application of the bending increments shows an increase over that obtained during the test of the uncoated cross-ply cylinder and a marked decrease over the rotation obtained during the test of the uncoated bias-ply cylinder. This difference in rotation can be attributed to the manner in which the inner bias-ply and outer cross-ply cylinders share the applied load. In comparing the results with those obtained using the bias-ply cylinder, a large improvement in the structural stiffness of the cylinders in bending is noted. Likewise, in comparing these same results with those obtained using the cross-ply cylinder, the two-ply cylinder shows a small loss in bending stiffness. This decrease in stiffness could result from the two plys not sharing the applied loads in the ratio which was considered ideal. If, for example, the bias-ply reacted a larger percentage of the internal pressure load than the assumed amount, this would result in the cross-ply cylinder being partially underloaded. Since most of the stiffness of the cylinder in bending is a result of the cross-ply, the reduction in cross-ply membrane load would likewise allow an increase in bending rotation. This effect is in part borne-out by the decrease in torsional rotation of the two-ply cylinder as compared to the bias-ply cylinder. Any decrease in torsional rotation results from the increased stiffness of the bias-ply due to an increase in its membrane load.

Appendix IX

FRUSTUM TEST REQUIREMENT

PROJECT FIRST

1.0 SCOPE

The scope of this requirement is to specify the general test methods for testing of all multifilament metal fabric frustum test specimens (SG 1109454) in accordance with the contractual requirements of Project FIRST, Contract Number AF 33(657)-10252.

2.0 TEST SPECIMENS

The test specimens shall be eleven (11) each 10-inch diameter (tapering to 7-inch diameter) x 30-inch long frustums per Dwg. No. 1109454. Specimens shall be serially numbered S/N P1 (P = Preliminary), 1, 2 . . . 10. Number P1 shall be fabricated from pilot run fabric, and the remainder from production run fabric.

3.0 GENERAL TEST PROCEDURES

3.1 TEST FACILITY

The test specimens shall be subjected to the tests shown in Table I, using test facility number 1110603, as shown in Figure 3 of this Requirement, utilizing calibrated gauges, indicators, and instruments per Air Force requirements along with such pneumatic and hydraulic load actuators and other accessories as may be required.

3.2 SEQUENCE OF TESTING

The sequence of testing has been chosen in such a way as to maximize the amount and relative importance of data acquired early in the testing sequence. Should premature failure or otherwise unsatisfactory test results be obtained, a decision to retest may be made, using a new specimen. In such a case, the new specimen shall be the next one available but the planned order to test specimens and test sequence shall not be disturbed so that, no matter how many retests are performed, the tests shall have been performed in the sequence given in Table I. The order of test sequence may be changed only upon agreement of the Project Engineer.

3.3 TEST SET-UP

3.3.1 GENERAL PROVISIONS

The end closures shall be assembled to the specimen making sure that there are no wrinkles which could cause leaks in the fabric in the clamping area. The clamps shall be positioned as close as possible to the wire rings at the ends of the specimen. Closures should be parallel to the ends of the specimen.

NOTE: The specimen shall not be buckled or creased during assembly.

During and after mounting the completed specimen and closure assemblies to the test fixture, the weight of the upper closure or loading jig shall be reacted by a counterweight. Before mounting the specimen in the test stand, the preliminary leak test procedure of paragraph 3. 3. 2 below shall be performed. Finally, the nitrogen supply line and a separate pressure gage or recorder line shall be connected to the specimen.

For high temperature test setups, the enclosure designed for this purpose shall be installed and purged of oxygen using dry nitorgen prior to and during heating the test specimen. Nitrogen atmosphere shall be maintained at conclusion of high temperature testing until test part temperature has dropped below 250°F. Thermocouples shall be installed as indicated in Figure 1 during test specimen fabrication.

3. 3. 2 PRELIMINARY LEAK TESTING

Before the nitrogen supply and pressure gage lines are connected to the test specimen closure fixture, they shall be connected together and a leak check of the pneumatic system shall be made at 50 to 60 spig. When the supply regulator is valved off, the system pressure drop shall be less than 1 psi in 10 minutes.

After assembly of the specimen and end closures per paragraph 3. 3. 1, internal nitrogen pressure, not to exceed 2 psig, shall be applied and leaks in both the specimen and the connections noted. Leaks that can be heard or located by running the hand over the perimeters of the end joints and pneumatic connections shall be rectified if they are not in the specimen proper. If no leaks are otherwise apparent, a solution of standard leak test fluid shall be applied and a further check made. Any leaks or coating blisters in the specimen itself shall be located by inspection, including use of the soap bubble technique, and recorded with the relative sizes and locations noted. The leakage record shall be reviewed by the Project Engineer before any subsequent test runs are made. The test specimen shall be returned to fabrication if leaks are significant enough to require repair before testing.

If the specimen is subjected to high temperature tests, it shall be purged of atmospheric oxygen before heating by bleeding nitrogen slowly through it for a minimum of one hour. The purged atmosphere shall be checked for oxygen content (not to exceed 1%) by an oxygen analyzer device.

3. 4 DOCUMENTATION

All data and observations shall be recorded, signed, and dated in SG laboratory notebooks or on data sheets with copies transmitted to Project files. Black and white still photographs and color movies shall be used to document all important facilities, tests, and test results at the direction of the Project Engineer.

4.0 PRECAUTIONARY NOTES

a. All test runs shall be witnessed by the Project Engineer or, at his option, a representative designated by him in each specific case.

b. Pressure in excess of 35 psig SHALL NOT be applied to a specimen at any time except during a witnessed test.

c. The specimens shall be handled and stored in a manner that will assure that no accidental creasing of the cloth or other damage will occur, either before and after testing.

d. Pressure and other loads cycling for pre-test or post-test check-out, photography, etc., shall be held to a minimum in order to prevent fatigue damage to the specimens.

e. During tests that conceivably could lead to pneumatic rupture, provisions shall be made to assure that no personnel injuries will result from flying parts of the test fixture or specimen. Note the anticipated minimum strength values in Table I.

f. Each specimen shall be identified with fabrication serial number and test number.

g. Only the Project Engineer is authorized to make changes (in writing) in test procedure or equipment and to determine final disposition of test specimens following test completion.

5.0 SPECIFIC TEST PROCEDURES – PERMEABILITY, PRESSURE, LOADS, AND PACKAGING

5.1 PERMEABILITY TESTING

5.1.1 ROOM TEMPERATURE PERMEABILITY TEST

With the specimen setup as described in paragraph 3.3, 5.0 psig internal pressure shall be applied to the specimen. The nitrogen supply shall then be closed off and the time required for a 1.0 psi pressure drop (to 4.0 psig) shall be recorded. This reading shall be repeated for two additional times. Next, the leak rate between 10.0 and 9.0 psig shall be similarly measured three times. The internal pressure shall be bled down slowly to approximately 1.0 psig if the test setup is to be allowed to stand idle for more than one hour.

5.1.2 MAXIMUM TEMPERATURE PERMEABILITY TEST

NOTE: The oxygen purging procedure of paragraph 3.3.2 is applicable to this test.

This test shall be performed on post-temperature test specimens during their heating cycle. Internal pressure shall be applied and maintained at 11 psig. At 8 minutes after specimen temperature at TC-5, Figure 1, rises above 700°F, the internal gas pressure supply shall be valved off and readings of the gas pressure taken at 30 second intervals for a total of 5 readings.

Following the last reading (at 10 minutes after TC-5 temperature rises above 700°F), the heat lamps shall be turned off.

5.1.3 POST TEMPERATURE PERMEABILITY TEST

Following establishment of stable "room" temperature conditions after completion of the maximum fabric temperature testing of paragraph 5.1.2, the permeability test, as described in paragraph 5.1.1, shall be performed.

5.2 PROOF PRESSURE TEST

5.2.1 ROOM TEMPERATURE PRESSURE TEST

Internal pressure shall be increased at a constant rate of approximately 0.5 to 1.0 psi/sec until 35.0 spig pressure is attained. The nitrogen supply shall then be closed off and the time required for a 1.0 psi pressure drop (to 34.0 psig) shall be recorded.

The minimum ultimate pressures of Table I should be noted. External loads superimposed on the pressure load would, of course, act to reduce these values. These ultimate values shall be considered during safety planning.

5.2.2 PRESSURE TEST AT MAXIMUM METAL FABRIC TEMPERATURE

With internal pressure held at 35 psig and radiant heat lamps positioned parallel to the specimen leading edge centerline, the heat lamps shall be turned on and the external fabric temperature (thermocouple TC-5, Figure 1) raised to 850°F maximum as quickly as equipment limitations will allow. After 10 minutes (elapsed time from 700°F), the lamps shall be turned off. The pressure shall be maintained at 35 psig during the entire heating cycle. Time vs temperature data shall be continuously recorded during the entire test run.

5.2.3 POST-TEMPERATURE PRESSURE TEST

Following completion of the permeability test described in paragraph 5.1.3, the pressure proof test, as described in paragraph 5.2.1, shall be performed.

5.3 ULTIMATE PRESSURE TESTING

5.3.1 ROOM TEMPERATURE BURST TEST

The pneumatic burst test shall be performed following the completion of all other room temperature tests. Internal pressure shall be increased

at a constant rate of approximately 1 to 2 psi/sec (subject to gas flow limitations of the nitrogen pressurizing system) until specimen failure occurs. In the event that a test equipment malfunction or specimen secondary failure occurs during the pressurizing run, which would compromise the validity of the test, every effort shall be made to stop the test run with minimum load-inflected damage to the specimen. The malfunction shall be corrected as well as practicable before attempting a rerun.

5.3.2 BURST TEST AT MAXIMUM METAL FABRIC TEMPERATURE

After maintaining component pressure at 35 psig and fabric temperature (TC-5) at 700 to 850°F for 10 minutes elapsed time, the internal pressure shall then be increased at a constant rate as described in paragraph 5.3.1 until failure occurs. Since the heating lamp will be shut off and a protective shield positioned in front of it before the pressure increase is begun, heat will cease to be added. The final temperature (as measured by TC-5), at the end of the 10 minute heating period, should be in the high part of the 700 to 850°F range, and then the pressure should be increased such that burst will likely occur before the temperature (TC-5) drops below 700°F.

5.3.3 POST-TEMPERATURE BURST TEST

This test shall be performed as described in paragraph 5.3.1.

5.4 DESIGN LOADS TESTING

5.4.1 COMBINED STATIC LIMIT LOAD TEST

The static design limit load tests shall all be performed at room temperature with 35 psig internal pressure. The maximum values given in Table II shall be applied proportional to one another and simultaneously in at least three equal increments. At each increment, deflection data shall be recorded. Deflection instrumentation locations are shown in Figure 1. At the completion of the limit load test, and without reducing the static loads, the procedure of paragraph 5.4.2.1 shall be carried out when required by the test matrix of Table I. If the ultimate load test is not required, the limit loads shall be reduced incrementally and deflection data shall be recorded again.

5.4.2 COMBINED STATIC ULTIMATE LOADS TEST

5.4.2.1 ROOM TEMPERATURE ULTIMATE LOADS TEST

The combined static loads shall be increased simultaneously and proportionately until failure occurs (buckling or rupture).

5.4.2.2 ULTIMATE LOADS TEST AT MAXIMUM METAL FABRIC TEM TEMPERATURE

This test shall be performed during the pressure proof test of paragraph 5.2.2. At approximately halfway through the 700°F to 850°F heating period, the combined static loads shall be increased at a constant rate until specimen failure, as defined above, occurs. If buckling failure (no gross

collapse or rupture) occurs, the loads shall be reduced and the design limit loads shall be maintained throughout the remainder of the heating cycle and then reduced. The heat lamp shall be turned off 10 minutes after the 700°F temperature is reached as in paragraph 5.2.2.

5.4.2.3 POST-TEMPERATURE ULTIMATE LOADS TEST

Following the completion of the other scheduled tests and when stable temperature conditions have been established, the post-temperature combined ultimate loads test shall be performed, as described in paragraph 5.4.2.1.

5.4.3 COMBINED FATIGUE LOADS TEST

5.4.3.1 FATIGUE LOADS AT MAXIMUM METAL FABRIC TEMPERATURE

This test shall be performed during the pressure proof test of paragraph 5.2.2. At 700°F fabric temperature as recorded by thermocouple TC-5, the combined limit loads, as given in Table II, shall be cycled from 0% to 100% and back to 0% at a uniform rate of 1.0 cycle per minute, for a total of 10 cycles. At the end of the last cycle, the heat lamps shall be turned off.

5.4.3.2 POST-TEMPERATURE FATIGUE LOADS TEST

Following completion of the proof pressure test of paragraph 5.2.3, the post-temperature fatigue loads test shall be performed by following the procedure of paragraph 5.4.3.1, except that no heat shall be applied to the specimen.

5.5 PACKAGING TESTING

5.5.1 PACKAGE CONFIGURATION DETERMINATION

The specimen (without wire end rings, if possible) shall be carefully folded and/or rolled at the direction of the Project Engineer so as to simulate possible packaging of the full-sized paraglider. When the folding and/or rolling has been completed, a container shall be made to enclose the specimen, simulating actual packaging requirements, and measurements of "packaged volume" shall be made with photographic documentation.

5.5.2 PACKAGED VIBRATION

The packaged specimen shall be mounted on a shaker table and vibrated along one axis through the following spectrum simulating the Saturn V launch condition:

Sinusoidal	1 Sweep at 3 Octaves/Min.
5 to 18.5 cps	0.154 inches, D.A.
19.5 to 100 cps	2.69 g, Constant

The specimen shall then be removed from its container and given a visual inspection to determine the extent of any test damage. Observation shall be reported in detail and photographs taken to document possible creased areas. Testing as required in the test matrix of Table I shall then continue.

Table I

PROJECT FIRST TEST MATRIX FOR 10-INCH DIAMETER FRUSTUMS - P/N 1109454

Test No.	Tests @ Room Temperature							Tests @ Max. Metal Fabric Temp.					Tests After Cooling					Frustum S/N
	Pm	Pr	Pk	PkV	LL	UL	PB	Pm	Pr	FL	UL	PB	Pm	Pr	FL	UL	PB	
P1	X	X					X											P1
1	X	X			X	X												1
2	X	X					X											3
3	X	X			X		X											2
4	X*	X*	X	X			X											6
5	X	X							X		X							8
9	X	X							X			X						7
10	X	X							X	X		X						9
6	X	X						X					X	X		X		4
7	X	X						X					X	X			X	5
8	X	X						X					X	X	X		X	10

*Repeated after PkV Test

Pm = Permeability Test
Pr = Pressure Test
Pk = Package
PkV = Packaged Vibration

LL = Limit Loads Test (Design)
UL = Ultimate Loads Test
PB = Pneumatic Burst Test
FL = Fatigue Loads Test (Ion)

NOTE: Minimum expected ultimate pressure values:

Ambient	Max Cloth Temp (850°F)	After Cooling
61 psi	49 psi	61 psi

Description of Tests in text:

Room Temp. Test	Para.	Max. Temp. Test	Para.	After Cooling Test	Para.
Pm	5.1.1	Pm	5.1.2	Pm	5.1.3
Pr	5.2.1	Pr	5.2.2	Pr	5.2.3
Pk	5.5.1	FL	5.4.3.1	FL	5.4.3.2
PkV	5.5.2	UL	5.4.2.2	UL	5.4.2.3
LL	5.4.1	PB	4.3.2	PB	5.3.3
UL	5.4.2.1				
PB	5.3.1				

Table II

DESIGN LIMIT LOADS ON 10-IN. TO 7-IN.
BY 30-IN. LONG FRUSTUMS

Design limit loads at the supported 10-in. diameter end of the specimen:

Torsion Moment	=	344 in. -lb
Bending Moment	=	4710 in. -lb
Shear Force	=	103 lb

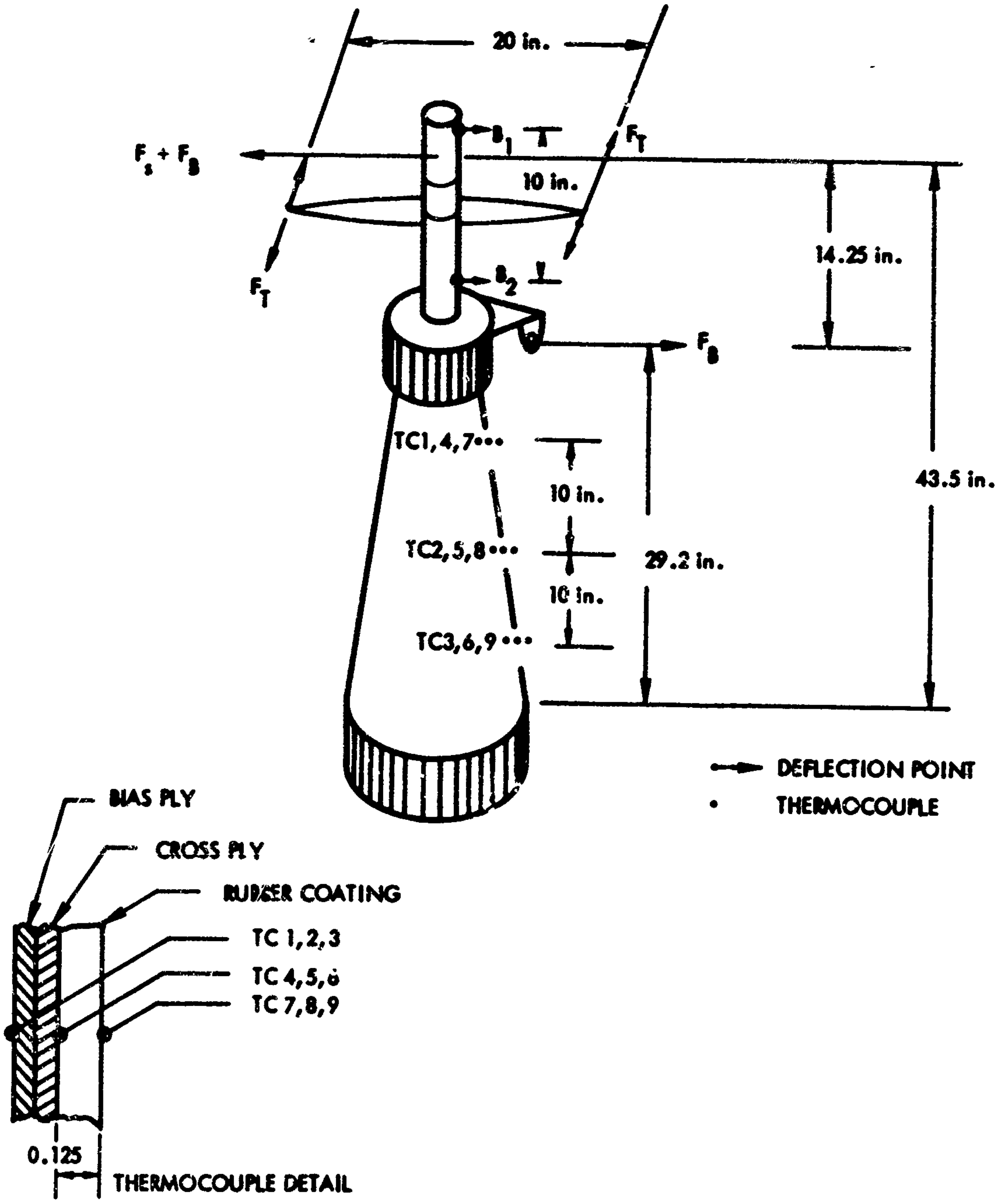


Figure 1. Frustum Instrumentation Location

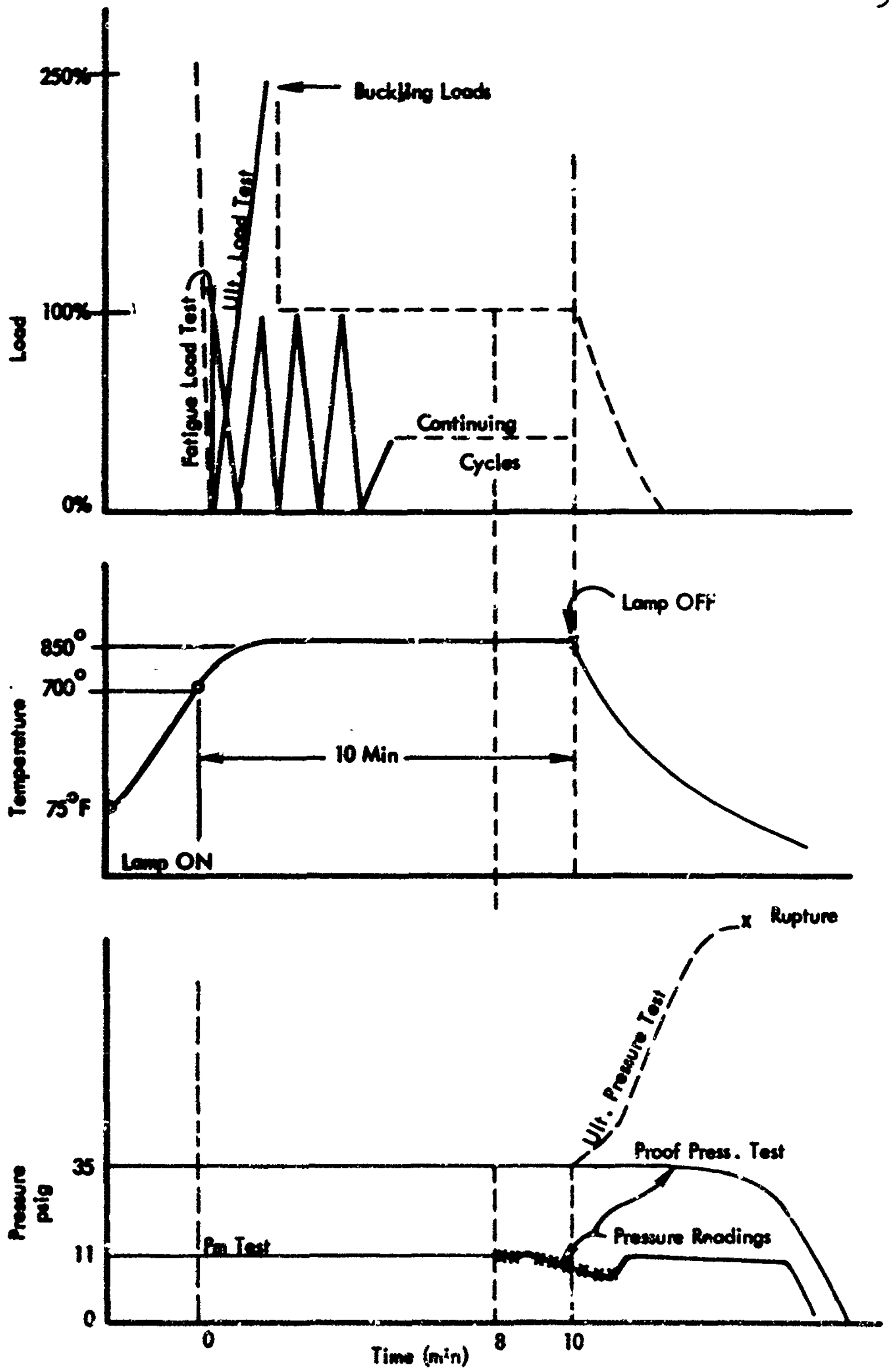
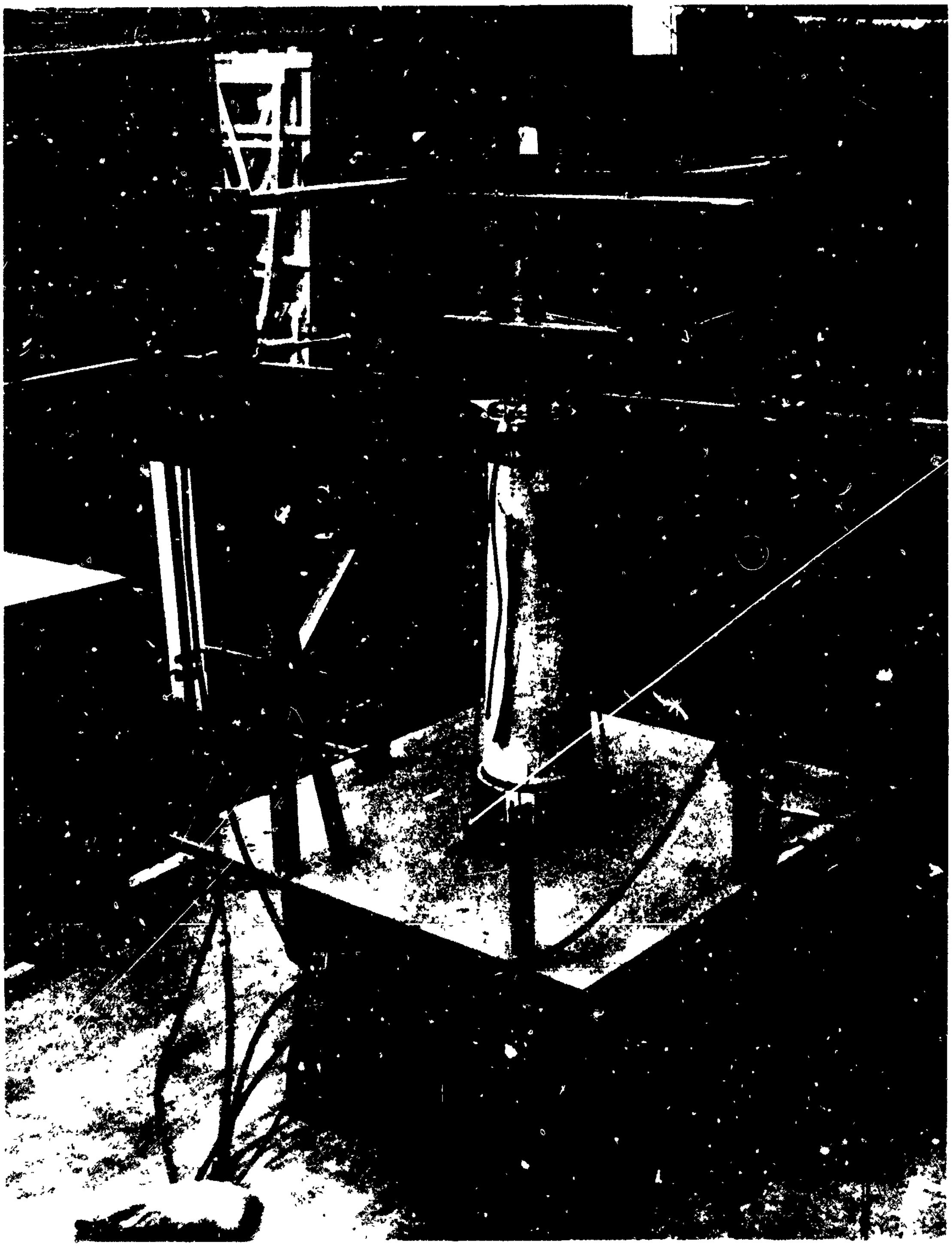


Figure 2. Anticipated Test Conditions



335-170

Figure 3. 10 Inch Diameter Frustum in Testing Fixture

Appendix X

FULL-SCALE BOOM TEST PLAN

SPACE SYSTEMS LABORATORIES

TEST PLANNING SHEET

DATE 21 April 1966

TEST TITLE: PROJECT FIRST FULL SCALE BOOM AMBIENT & HI-TEMPERATURE TESTS

JOB NO. 335	TO BE COMPLETED BY ENG. LABORATORIES
PROJECT ENGINEER J. F. Keville	TEST ENGINEER J. S. Haynes
DESIRED START DATE 5/30/66	EST. SALARY HOURS
PROJECT APPROVAL JFKeville	EST. HOURLY HOURS
TYPE OF TEST	EST. MATERIAL DOLLARS
RESEARCH AND/OR DEVELOPMENT X	TEST START DATE
QUALIFICATION	TEST PLAN NO. 0266-3
	SUPVR. APPROVAL J. H. Fredy, Jr.
ACCEPTANCE	C.C. A. F. Baca (2), C. Barton, G. H. Fredy, J. G. Guidero, J. S. Haynes, J. Crawford, J. F. Keville (2), W. A. Makofske, A. [illegible]yer, H. Wright, ELD File 335.2.2 (2+Master)

TEST ENVIRONMENTS

TEMPERATURE Ambient to 850°F *

*(Measured at reinforcing fabric)

PRESSURE Internal Pressure = 11 psig

VIBRATION X TYPE 0 - 250 cps, 0.25 to 2.69 'g' sine input

ACCELERATION

SHOCK

HUMIDITY

SALT SPRAY

SAND & DUST

OTHER Load deflection and pressurization

TEST SPECIMEN DISPOSITION Project office responsibility to be ultimately placed in Bonded Stores for Air Force disposition.

JGG:rd

*(Measured at reinforcing fabric)

SGC 115-02(8/63) - Page 1

1.0 TEST OBJECTIVE

The objective of these tests is to determine the adequacy of design and fabrication technology of the Project FIRST proposed paraglider in accordance with the requirements of Contract No. AF 33(657)-10252. The test specimen is a full-scale leading edge boom using rubber impregnated and coated multifilament metal fabric as the material. Tests shall be performed in the specified sequence simulating the conditions encountered during predicted, normal reentry flight.

2.0 TEST SPECIMEN AND SETUP

The leading edge boom (SGC 1109452) will be set up as shown in Figures 1 thru 4, to complete the requirements of the proof pressure permeability, flight vibration, and static limit test loads. The boom will be cantilevered from a stationary support using a clamped closure on the 32 inch large end of the boom where a two-ply cuff and end wire hoop are provided. The static loads will be introduced via a load distributing whiffle-tree into the wing membrane tabs which are an integral attachment of the boom. Displacement transducers capable of measuring displacements up to 10 inches (5.22 @100%) with accuracies to $\pm$ 0.03 inches will be used to measure the displacements, due to bending and torsion loads applied through the membrane tab. General provisions for care in handling and mounting shall be the same as provided for frustum testing in requirement 335R-7. Pressure in the boom shall be bled down to approximately 1.0 psig if the set up is allowed to stand idle for more than one hour.

3.0 TEST PROCEDURES - AMBIENT TEMPERATURE

3.1 DOCUMENTATION

All data and observations shall be recorded, signed, and dated in SGC laboratory notebooks or on data sheets with copies transmitted to Project files. Black and white still photographs and color movies shall be used to document all important facility tests, and test results at the direction of the Project Engineer.

3.2 PRECAUTIONARY NOTES

a. All test runs shall be witnessed by the Project Engineer or, at his option, a representative designated by him in each specific case.

b. Pressure in excess of 5 psig SHALL NOT be applied to a specimen at any time except during a witnessed test.

c. The specimens shall be handled and stored in a manner that will assure that no accidental creasing of the cloth or other damage will occur, both before and after testing.

d. Pressure and other loads cycling for pre-test or post-test checkout, photography, etc., shall be held to a minimum in order to prevent fatigue damage to the specimens.

e. During tests that conceivably could lead to pneumatic rupture, provisions shall be made to assure that no personal injuries will result from flying parts of the test fixture or specimen. Note the anticipated minimum strength values in Table I.

f. The specimen shall be identified with the fabrication serial number and test number.

g. Only the Project Engineer is authorized to make changes (in writing) in test procedure or equipment and to determine final disposition of test specimens following test completion.

3.3 PRESSURE PROOF AND PERMEABILITY TEST

Upon completion of the test setup as shown in Figure 1, nitrogen pressure of 0.5 psig shall be applied to check the boom and pressurization system for leaks. A soap solution may be used to determine any small leaks. After the system has been leak checked, the pressure shall be increased in 2 psi increments to 11 psig. Diametrical and length measurements shall be taken after each increasing increment.

Upon reaching 5.0 psig, the time required for a 1.0 psi pressure drop from 5.0 (to 4.0 psig) shall be recorded. The reading shall be repeated two additional times. Pressure shall then continue to be increased in 2 psi increments as above.

Upon reaching 11 psig, the pressurization valve shall be closed for 30 minutes to determine the leakage of gas through the walls of the specimen. The pressure drop shall be recorded at each 5 minute interval. Should the pressure drop be greater than anticipated, pressure drop readings shall be recorded at closer intervals.

The leakage record shall be reviewed by the Project Engineer before any subsequent tests are performed. The boom shall be returned to fabrication if leaks are significant enough to require repair before further testing. If repairs are made, the above permeability and proof pressure tests shall be repeated.

3.4 PACKAGE TESTING

3.4.1 FOLD TEST

The boom is to be carefully folded and/or rolled in a manner approved by the Project Engineer which will be characteristic of the manner of packaging the full sized paraglider. Once this package configuration has been made the shape will be constrained while a metal container is made to encapsulate the

specimen, in simulation of a full scale paraglider package. Measurements of "packaged volume" shall be made with suitable photographic documentation.

3.4.2 PACKAGED VIBRATION

The packaged specimen in the container, properly padded if required, is to be installed on the shaker table and the package vibrated along one axis at:

Sinusoidal	1 Sweep at 3 Octaves/Min.
5 to 18.5 cps	0.154 in. D.A.
18.5 to 100 cps	2.69 'g' Constant

A post-test visual inspection of the specimen shall be made, documented photographically, both before and after deploying the boom to the inflated shape. The procedures of paragraph 3.3 shall be repeated.

3.5 VIBRATION TEST

The object of the vibration tests will be to determine the fundamental resonant frequency of the specimen, due to lateral vibrations of a low input level. While maintaining an input level of ½ 'g' or less, (via ref. accelerometers on the mounting jig), the frequency shall be swept from 0 to 250 cps, in 3 min., with the output of accelerometers being recorded. (See Figure 2.) Upon determination of resonant frequency by the output accelerometers, photographs shall be taken with the aid of a strobe light and still camera, to determine any unusual mode shapes (i.e., cross sectional and/or longitudinal) of the boom. An internal pressure of 11 psig shall be maintained throughout the vibration.

3.6 STATIC LIMIT LOADS TEST

The static limit loads test setup is shown in Figure 3. The internal pressure shall be maintained at 11 psig and the external, lateral load increased in 20% increments to 100% of combined limit loads. Deflection data shall be taken at each load increment.

Should any yielding, buckling, or damaging deformation be detected during the test, the loading will be stopped so as not to damage the specimen for the elevated temperature and post-temperature tests. The external loads shall be decreased to zero, while maintaining 11 psig internal pressure, and deflection measurements shall be made to determine any residual set.

3.7 PRESSURE & PERMEABILITY TEST

After completion of the ambient temperature tests and maintaining the same test setup, the permeability and proof pressure test of paragraph 3.3 shall be repeated in total.

3.8 CYCLIC STATIC LOADS TEST AT ELEVATED TEMPERATURE

Upon completion of the pressure and permeability tests of para. 3.7, the infrared heating lamps and inert atmosphere enclosure will be set up to run the elevated temperature tests. Nitrogen gas will be bled into the enclosure to ensure an "inert" atmosphere of less than 1.0% (by volume) oxygen as measured by suitable test equipment.

NOTE: Eleven (11) psig internal pressure will be maintained throughout the high temperature tests except for the pressure test period per paragraph 3.10.

The temperature will be increased at the maximum heating rate of the lamps. At 700°F as measured by at least two thermocouples attached to the fabric, the 100% lateral membrane load of 340 lb. will be applied as shown in Figure 1 and cycled ten (10) times from 0 to 100% at a rate to complete one cycle per minute regardless of the temperature obtained. However, 850°F metal fabric temperature will not be exceeded. One (1) displacement transducer (1 = 10") as shown in Figure 5 will be continuously recorded during the heating and cycling test.

3.9 VIBRATION TEST AT ELEVATED TEMPERATURE

Upon completion of the lateral load cycling test, the lateral loading apparatus will be removed and the specimen will be subjected to a fundamental natural frequency in the same manner as previously determined at room ambient temperature, to determine the effect of vibration after the silicone rubber and metal fabric has reached maximum temperature. This test should occupy 2.0 minutes maximum.

3.10 PRESSURE TEST AT ELEVATED TEMPERATURE

After completion of the vibration test, a permeability test shall be run by closing off the nitrogen pressurization valve and noting the drop in pressure for a 1 minute time interval and internal gas temperatures shall be noted at the beginning and end of the 1 minute period. The internal pressure shall then be increased back to 11.0 psig and maintained.

All operations mentioned in paragraphs 3.8, 3.9 and 3.10, shall be completed in one heating, and shall be coordinated to not exceed a time limit of 15 minutes after the metal fabric has reached 700°F. (See Figure 5). Should the specimen burst or fail during these tests, photographs will be taken of the failed part. At the conclusion of the 15 minutes heating period, the heating lamps shall be shut off and the part allowed to cool to room temperature while remaining in the nitrogen purged enclosure.

3.11 TESTS AFTER COOLING

Upon completion of the elevated temperature tests, the permeability (paragraph 3.3) and pressure vibration (paragraph 3.9), and cycling of static loads (paragraph 3.8) will be repeated, to determine the structural capability

of the specimen after being subjected to simulated reentry temperature.

3.12 STATIC ULTIMATE LOADS AND ULTIMATE PRESSURE TEST AFTER COOLING

With the internal pressure maintained at 11 psig, the lateral loads will be increased in 10% increments beyond 100% (up to 300% only) until visual buckling or failure occurs. Should the specimen not rupture during the static load to failure test, the specimen will be failed by reducing the external load to zero and increasing the internal pressure at 10.0 psi/minute maximum beyond 11 psig until specimen burst. Photographs (including high speed movie film during burst test, if possible) of the failure will be taken to show the nature of failure.

TABLE I

LOADING SEQUENCE FOR STATIC LOAD DEFLECTION TEST

Limit %	Transverse Bending Load lb.	Pressure psig
0	0	11.0
20	68	↑
40	136	
60	204	
80	272	
100	340	
80	272	
60	204	
40	136	
20	68	↓
0	0	11.0

100% Limit Loads

Internal Pressure . . . . . 11.0 psig

Lateral Load . . . . 340 lbs

Respective loads at supported 32" diameter end of boom at 100% combined external load:

Torsion Moment	=	3,760	in. lb.
Bending Moment	=	42,183	in. lb.
Shear Force	=	340	lb.

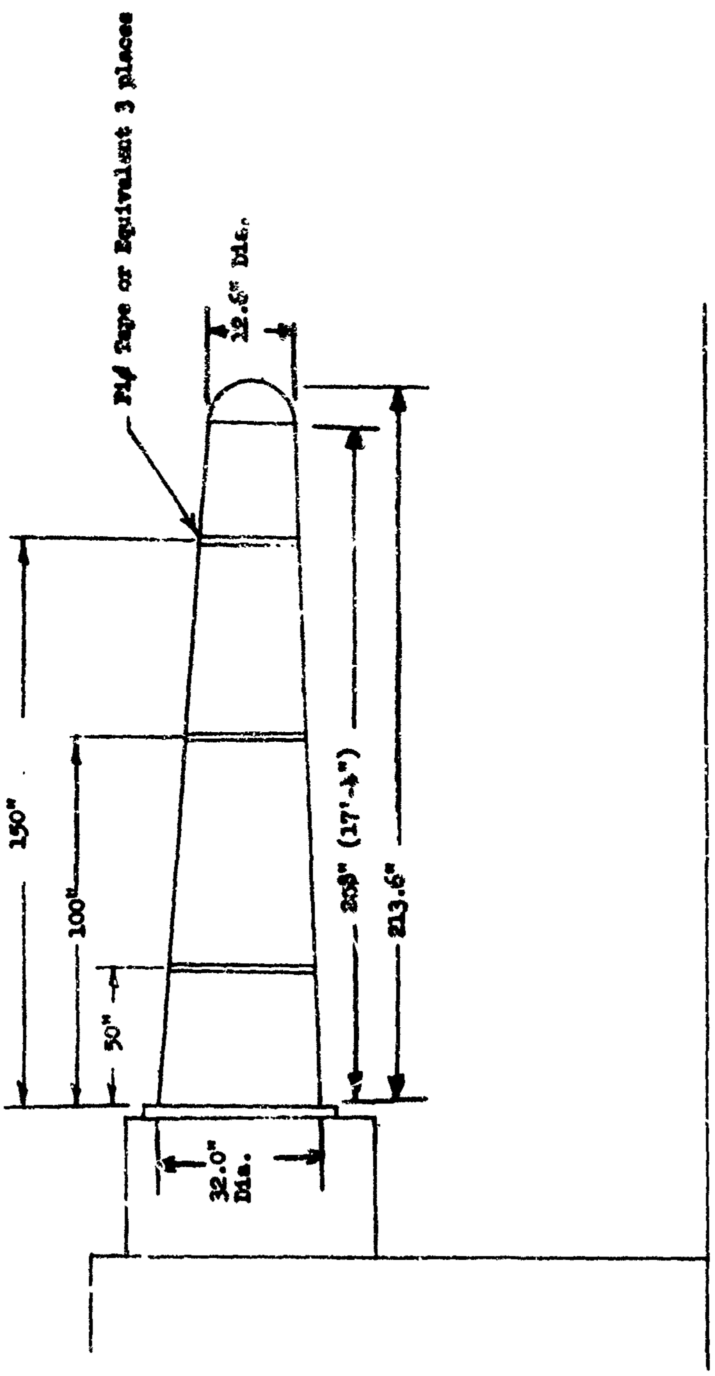


Figure 1 - Diametrical Measurement Locations Room Temperature

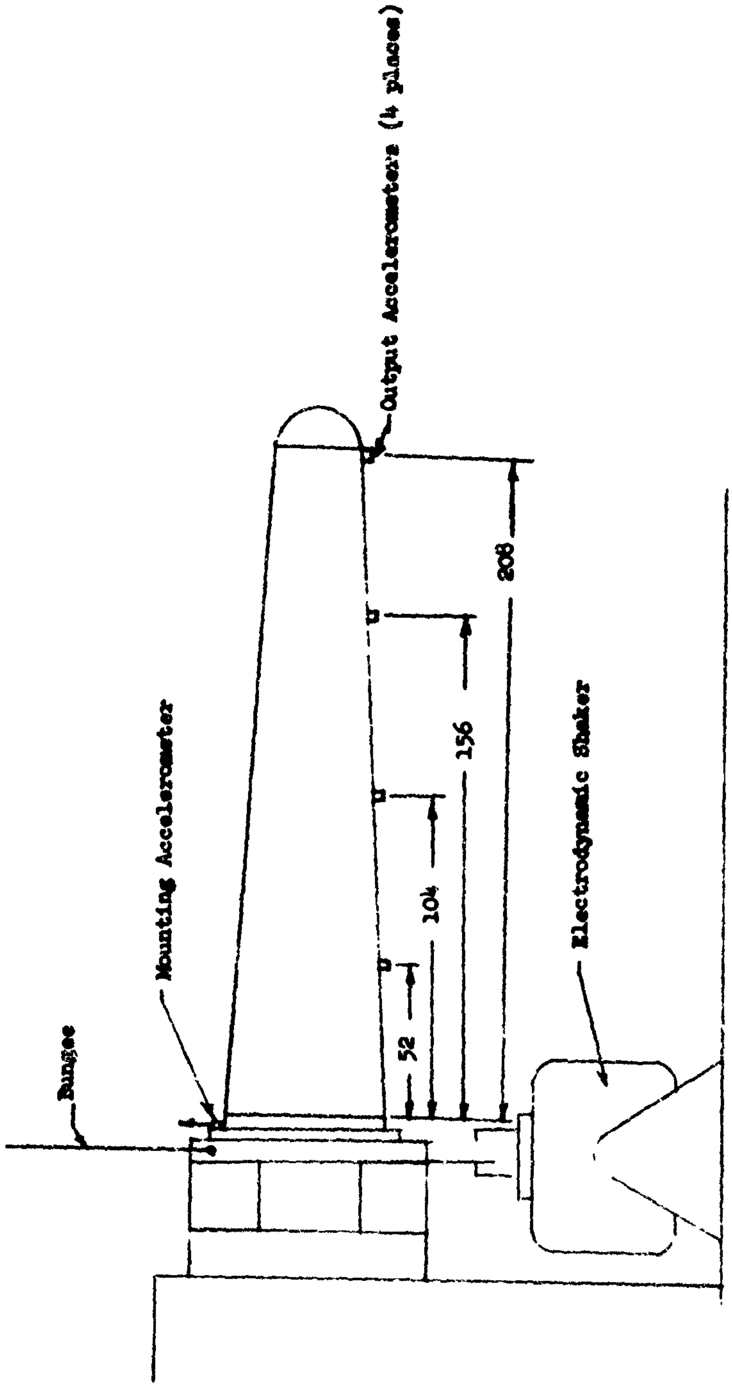


Figure 2 - Resonant Vibration Instrumentation Locations

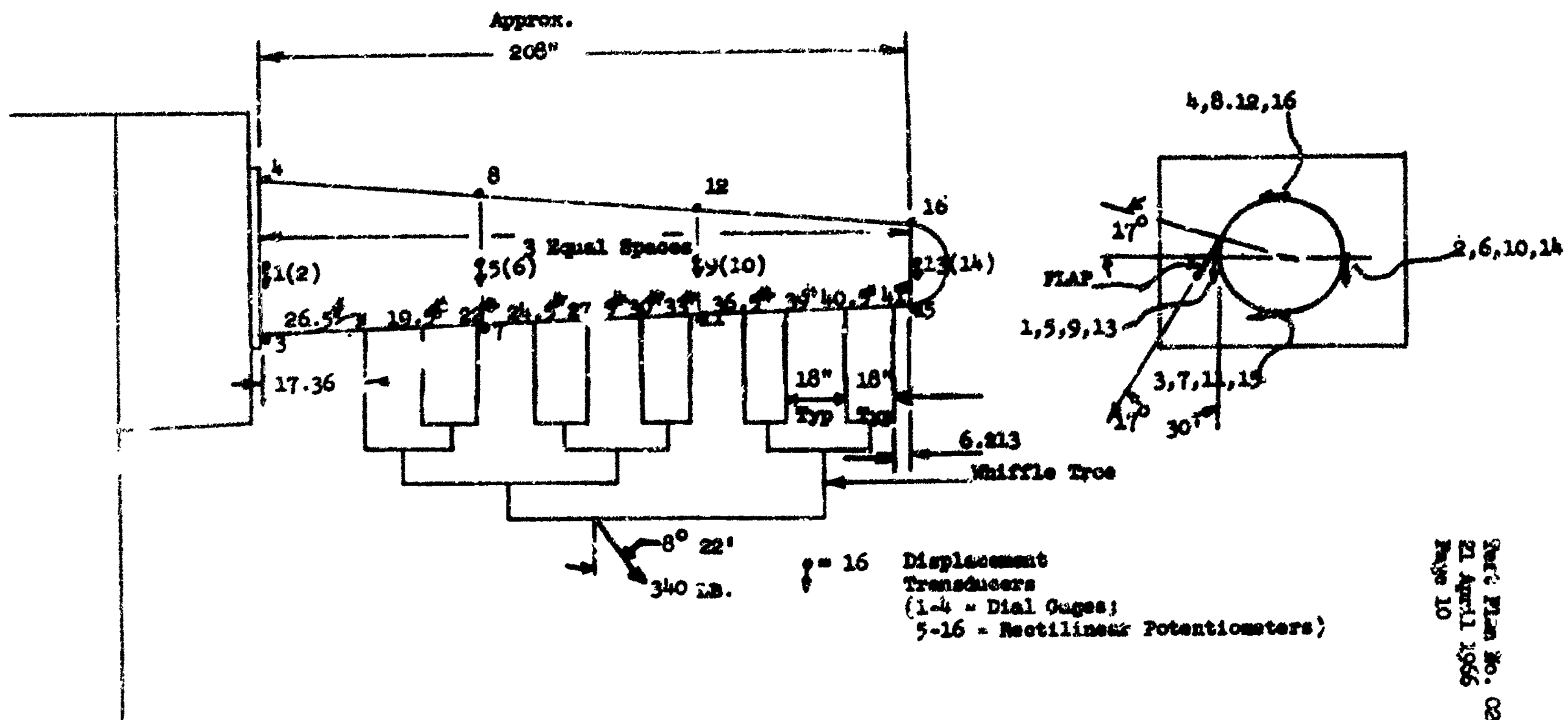


Figure 3 - Deflection Instrumentation and Loading Points - Locations and Directions.

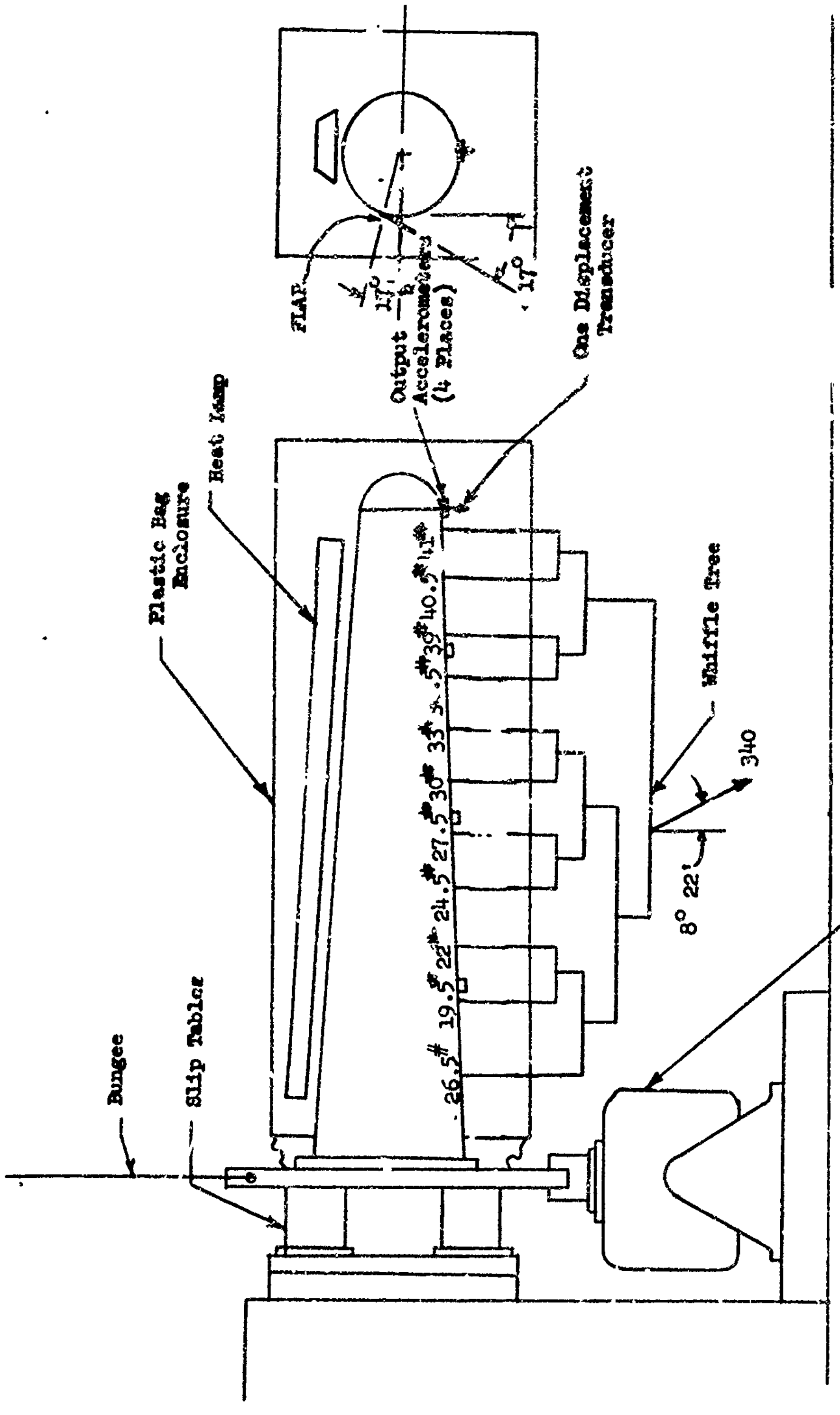
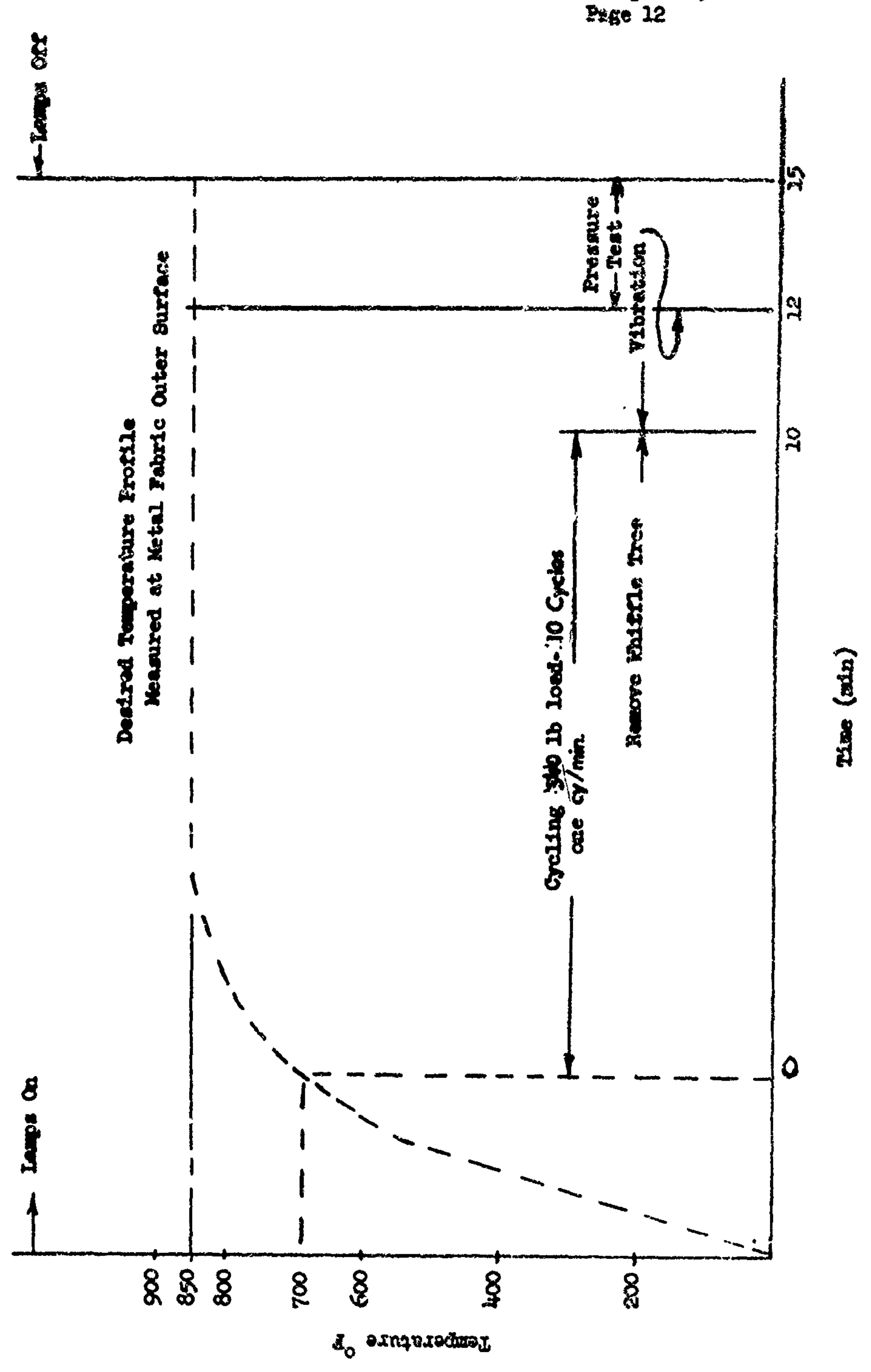


FIGURE 1
Boom High Temperature Test Setup

FIGURE 5
Time Temperature Profile



Appendix XI

PACKAGE VIBRATION TEST OF BOOM

TEST TITLE	PREPARED FOR	REPORT NUMBER
Packaged Vibration Test of One (1) Project First Boom Assembly, Part No. 1109452	Space General Corporation 9200 East Flair Drive El Monte, California Attn. Mr. John Guidaro	4727 PAGE 1 OF 2 CEL

REFERENCES: (a) Space-General Corporation Purchase Order No. 335-P67195.
(b) SGC Test Planning Sheet No. 0266-3 dated 21 April 1966, titled: "Project First Full Scale Boom Ambient and High Temperature Test".

This is to certify that one (1) Project First Boom Assembly, Part No. 1109452, has been subjected to the Packaged Vibration Test set forth in Paragraph 3.4.2 of Reference (b) as required by Reference (a).

Specifically, the test specimen, while packaged in its container, was rigidly mounted to a vibration test machine as shown in Photograph 1. Thereafter, the test specimen was subjected to one logarithmic sweep upward between the frequency limits of 5-100 cps. The sweep rate was maintained at three octaves per minute. Vibratory inputs maintained during the test were as follows:

Frequency (cps)	Vibration Input
5 - 18.5	0.154" DA
18.5 - 100	2.69 G

At the conclusion of the aforementioned Vibration Test, the test specimen was removed from the vibration table and the container was examined for any evidence of damage. None whatsoever was noted. The test specimen was returned to Space-General Corporation for removal and examination of the boom assembly.

Enclosure No. 1 sets forth a list of equipment utilized to perform the Vibration Test.

STATE OF CALIFORNIA
COUNTY OF LOS ANGELES } ss

A. E. Gelso being duly sworn, deposes and says: That the information contained in this report is the result of complete and carefully conducted tests and is to the best of his knowledge true and correct in all respects.

[signature]

SUBSCRIBED and sworn to before me this 14th day of June, 1966

[signature]
Notary Public in and for the County of Los Angeles, State of California
My Commission Expires 21 April 1968

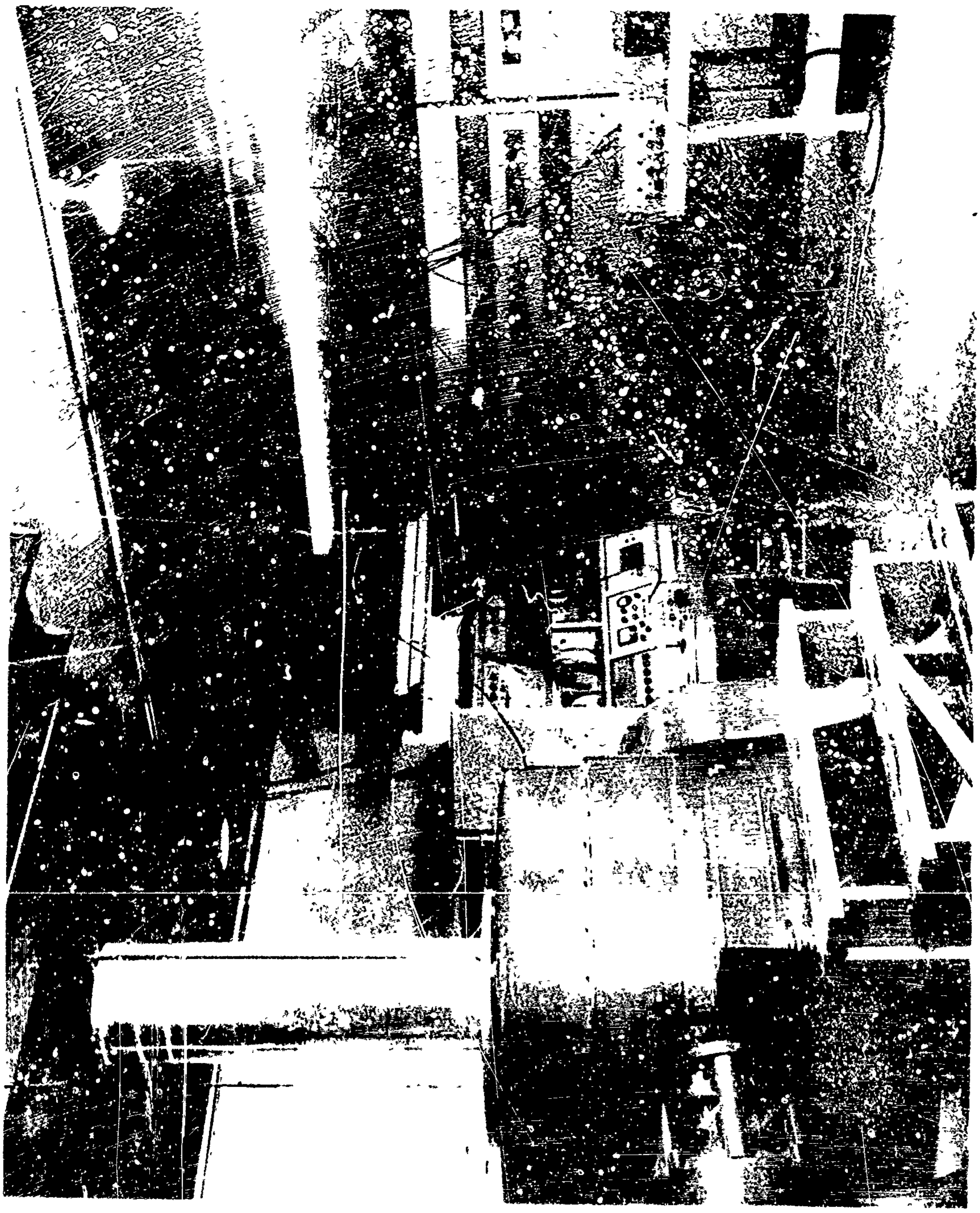
Date 14 June 1966
Contract No.
Customer P.O. No. 335-P67195
Test Engineer [signature]
C. M. Swatek, Jr.
CEL Q.C. Mgr. [signature]
Under Surveillance of

ENCLOSURE I

DESCRIPTION OF TEST EQUIPMENT

Equipment Description	Manufacturer, S/N, CEL No.	Calibration Period
Exciter, Vibration Range: 5 to 2000 cps 28,000 Force lbs/sine 25,000 Force lbs/random Accuracy: Waveform distortion: ± 15% fs output	MB Electronics M/N C-210 CEL No. 2-156	6 months
Power Supply, Vibration Range: 5 to 5000 cps 78 kw output Accuracy: Externally instrumented	MB Electronics M/N 999 S/N 105 CEL No. 2-161	NA
Control Console, Vibration Range: 5 to 10,000 cps Accuracy: ± 5.0% rdg.	MB Electronics M/N T 68 CEL No. 2-162	1 month
Accelerometer, Piezo-electric Range: 0.15 to 10,000 G Sensitivity: 15 rms mv/G Peak - Freq. Response: 2 cps to 7 kc -54°C to +110°C Accuracy: Linearity: ±2.0% rdg.	Endevco M/N 2213C S/N LB 46 CEL No. 3-436-1	Prior to use

All equipment utilized was currently in calibration as outlined in Component Evaluation Laboratories' Quality Control Manual.



SGC/975

Figure 1. Vibration Test System

Appendix XII

FULL SCALE APEX TEST PLAN

SPACE SYSTEMS LABORATORIES
TEST PLANNING SHEET

DATE 21 September 1966

TEST TITLE: Project FIRST Full Scale Apex Ambient Test Plan

JOB NO. 335

PROJECT ENGINEER 10/17/66

DESIRED START DATE

PROJECT APPROVAL

TYPE OF TEST

RESEARCH AND/OR DEVELOPMENT X

QUALIFICATION

ACCEPTANCE

TO BE COMPLETED BY ENG. LABORATORIES

TEST ENGINEER J. S. Haynes

EST. SALARY HOURS

EST. HOURLY HOURS

EST. MATERIAL DOLLARS

TEST START DATE

TEST PLAN NO. 0966-1

SUPVR. APPROVAL G. H. Fredy, Jr.

C.C. A. Baca (2), J. Crawford, G.H. Fredy, J. Guidero, J.S. Haynes, J.F. Keville, W.A. Makofske, J. Schrink, A. Speyer, ELD File 335.2.2 (2+Master)

TEST ENVIRONMENTS

TEMPERATURE Ambient

PRESSURE Internal Pressure = 11 psig

VIBRATION TYPE

ACCELERATION

SHOCK

HUMIDITY

SALT SPRAY

SAND & DUST

OTHER Load deflection and pressurization

TEST SPECIMEN DISPOSITION Project office responsibility to be ultimately placed in Bonded Stores for Air Force disposition.

Appendix XII

PROJECT FIRST FULL SCALE APEX AMBIENT TEST PLAN

1.0 TEST OBJECTIVE

The objective of these tests is to determine the adequacy of design and fabrication technology of the Project FIRST proposed paraglider in accordance with the requirements of Contract No. AF 33 (657)-10252. The test specimen is a full-scale Apex assembly using silicone rubber impregnated multifilament metal fabric as the material. Tests shall be performed in the specified sequence simulating some of the conditions encountered during predicted, normal reentry flight.

2.0 TEST SPECIMEN AND SETUP

The Apex (SGC 1109453) will be set up as shown in Figure 1, to complete the requirements of the proof pressure, permeability and static limit loads tests. The Apex will be cantilevered from a stationary support using a clamped closure on the 32 inch center stub boom where a two-ply cuff and end wire hoop are provided. Clamped closures will be installed on the two leading edge stub booms and these closures will be supported from the test fixture. The static loads will be introduced via the ends of the two clamped closures into the Apex assembly. Displacement transducers capable of measuring displacements up to 10 inches (5.22 @ 100%) with accuracies to ± 0.03 inches will be used to measure the displacements, due to bending, shear and torsion loads applied through the stub booms. General provisions for care in handling and mounting shall be the same as provided for frustum testing in requirement 335R-7. Pressure in the Apex shall be bled down to approximately 1.0 psig, if the setup is allowed to stand idle for more than one hour.

3.0 TEST PROCEDURES - AMBIENT TEMPERATURE

3.1 DOCUMENTATION

All data and observations shall be recorded, signed, and dated in SGC laboratory notebooks or in data sheets with copies transmitted to Project files. Black and white still photographs and color movies shall be used to document all important facility tests, and test results at the direction of the Project Engineer.

3.2 PRECAUTIONARY NOTES

a. All test runs shall be witnessed by the Project Engineer or, at his option, a representative designated by him in each specific case.

b. Pressure in excess of 5 psig SHALL NOT be applied to a specimen at any time except during a witnessed test.

c. The specimen shall be handled and stored in a manner that will assure that no accidental creasing of the cloth or other damage will occur, both before and after testing.

d. Pressure and other loads for pre-test or post-test checkout, photography, etc., shall be held to a minimum in order to prevent fatigue damage to the specimens.

e. During tests that conceivably could lead to pneumatic rupture, provisions shall be made to assure that no injuries will result from flying parts of the test fixture or specimen. Note the anticipated minimum strength values in Table I.

f. The specimen shall be identified with the fabrication serial number and test number.

g. Only the Project Engineer is authorized to make changes (in writing) in test procedure or equipment and to determine final disposition of test specimens following test completion.

3.3 PRESSURE PROOF AND PERMEABILITY TEST

Upon completion of the test setup as shown in Figure 1,* nitrogen pressure of 0.5 psig shall be applied to check the Apex for leaks. The pressurization system shall be checked at 50 psi before testing the Apex assembly. Only water may be used to determine any small Apex leaks. After the Apex system has been leak checked, the pressure shall be increased in 2 psi increments to 11 psig.

Upon reaching 5.0 psig, the time required for a 1.0 psi pressure drop from 5.0 (to 4.0 psig) shall be recorded. The reading shall be repeated two additional times. Pressure shall then continue to be increased in 2 psi increments as above.

Upon reaching 11 psig, the pressurization valve shall be closed for 30 minutes to determine the leakage of gas through the walls of the specimen. The pressure drop shall be recorded at each 5 minute interval. Should the pressure drop be greater than anticipated, pressure drop readings shall be recorded at closer intervals.

The leakage record shall be reviewed by the Project Engineer before any subsequent tests are performed. The Apex shall be returned to fabrication if leaks are significant enough to require repair before further testing. If repairs are made, the above permeability and proof pressure test shall be repeated.

3.4 PACKAGE FOLD TEST

The Apex is to be carefully folded and/or rolled in a manner approved by the Project Engineer which will be characteristic of the manner of packaging the full sized paraglider. Once this package configuration has been made, the shape will be constrained and measurements of the "packaged volume" shall be made and suitable photographic documentation will be taken.

3.5 STATIC LIMIT LOADS TEST

The Apex will be remounted on the test fixture and the procedures of Paragraph 3.3 shall be repeated. The static limit loads test setup is shown in Figure 1. The internal pressure shall be maintained at 11 psig, and the external, lateral load increased in 20% increments to 100% of combined limit loads. Deflection data shall be taken at each load increment (see Table I).

Should any yielding, buckling, or damaging deformation be detected during the test, the loading will be stopped so as not to damage the specimen prior to subsequent tests. The external loads shall be decreased to zero, while maintaining 11 psig internal pressure, and deflection measurements shall be made to determine any residual set.

3.6 STATIC ULTIMATE LOADS AND ULTIMATE PRESSURE TEST

With the internal pressure maintained at 11 psig, the lateral loads will be increased in 10% increments beyond 100% (up to 300% only) until visual buckling or failure occurs. Should the specimen not rupture during the static load to failure test, the specimen will be failed by reducing the external load to zero and increasing the internal pressure at 10.0 psi/minute maximum beyond 11 psig until specimen bursts. Photographs (including high-speed movie film during burst test, if possible) of the failure will be taken to show the nature of failure.

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*Less test loading members and displacement transducers.

Table I

LOADING SEQUENCE FOR STATIC LOAD DEFLECTION TEST

Limit %	Transverse Bending Load lb.	Pressure psig
0	0	11.0
20	68	
40	136	
60	204	
80	272	
100	340	
80	272	
60	204	
40	136	
20	68	
0	0	

100% Limit Loads

Internal Pressure . . . . 11.0 psig

Lateral Load . . . . 340 lbs

Respective loads at point of tangency of Apex at 100% combined external loads:

Torsion Moment = 2,084 in. lb.

Bending Moment = 42,500 in. lb.

Shear Force = 340 lb. @6.13 inches from ℄

Anticipated minimum ultimate load values

Pressure . . . . 22 psig

Lateral Load . . . . 800 lbs

Unclassified

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Manufacturing Technology Division Air Force Materials Laboratory RTD, AFSC, WPAFB, Ohio

13. ABSTRACT This study, fabrication and test program was undertaken to determine the most suitable structural design, using available materials, for inflatable re-entry vehicles and space structures, to develop suitable manufacturing processes and techniques, and to perform tests on the resulting components of a typical re-entry paraglider. The results are applicable to other types of structures. This final technical report covers the period 15 January 1963 to 15 January 1967. Materials system development was conducted in conjunction with re-entry, aero-thermodynamic studies and vehicle structural design. A two-ply, ultra-fine, multifilament, nickel-chromium metal fabric, impregnated and coated with two different types of silicone rubber, was chosen as the basic structural and inflatable membrane of the re-entry vehicle. Major areas of technology advancement included development of manufacturing and processing techniques for the utilization of ultra-fine metal filament in the manufacture of special metal fabrics; stress analysis, and confirmation by test, of structures constructed of anisotropic woven materials; design and construction of a special, deep-throat, semi-automatic metal fabric welder capable of producing flexible, welded seams of approximately 90 percent efficiency in two through five layers of metal fabric; techniques for thorough impregnation and coating of metal fabric with high-temperature and ablative silicone elastomers, and fabrication methods for the construction of expandable space structures.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Paraglider Design						
Space Rescue						
Metal Fabric						
Metal Fabric Joining						
Silicone Rubber Applications						
Materials for Re-entry						
Expandable Structures						
Paraglider Components Test						
Re-entry Vehicle						
Atmospheric Re-entry						
Manned Spacecraft						
Re-entry Thermodynamics						
Aerodynamic Configurations						
Ultrafine Wire						
Metal Yarn						
Resistance Welder						
Metal Fabric Welding						